Proceedings of the XXXth International online conference Research for Furniture Industry

22–23 September 2022 Poznań, Poland

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Dedication

The XXXth International Conference Research for Furniture Industry was dedicated to our distinguished professor Hassan Efe.

A LIFE DEDICATED TO FURNITURE
Prof. Dr. Hasan Efe (1955–2021)

Prof. Dr. Hasan Efe was born in 1955 in Ankara, Türkiye. He completed his high school, undergraduate, master of science, and doctorate educations in furniture design and engineering. In the first years of his working life, he worked as a school director in vocational high schools affiliated with the Ministry of National Education. Later, he worked as an academician at Gazi University, Faculty of Technical Education, for many years.

In his academic life, Dr. Efe has published many important scientific studies on furniture history, furniture design, furniture and interior ergonomics, and furniture engineering, as well as providing training for many students/researchers in these fields. For many years, he worked as a visiting scholar in Japan, Germany, and the United States of America to conduct scientific studies in his fields.

Dr. Efe was an extraordinary person who felt the "Hasan Efe" trend everywhere. Behind his sweet-hard look, he had a soft, emotional, and brave heart, making you feel valued, trusted, and loved. He was an intellectual, extremely disciplined, and hardworking scientist. Justice was his greatest virtue. Dr. Efe was married and had two daughters and a son. He also had seven grandkids.

Prof. Dr. Hasan Efe was the colorful face of scientific activities such as congresses, conferences, and symposiums. We feel his absence so deeply, and we miss him so much.

Rest in peace "HASAN HOCA"

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Invited Speakers

M.Sc. Erinc Mertoglu; Mertoğlu Playgrounds and Urban Furniture-ANKARA; Türkiye; "Evolution of design, manufacturing and market needs urban furniture in Turkiye".

M.Sc. Michał Strzelecki; Head of Polish Chamber of Commerce of Furniture Manufacturers; Warsaw; Poland; "Polish furniture sector-Challenges and threats".

Prof. Dr. Eva Haviarova; Department of Forestry and Natural Resources; Purdue University; Indiana; USA; "Teaching Approach for Integrated Furniture Design and Product Development".

Dr. Wengang Hu; College of Furnishings and Industrial Design; Nanjing Forestry University; China; "Numerical study on mortise-and-tenon joint wood frame furniture: Modelling and optimization".

Prof. Dr. Sc. Silvana Prekrat; Faculty of Forestry and Wood Technology; University of Zagreb; Croatia; "The research on student's performance and acquired skills in technical drawing for furniture production".

Contents

Preface

The XXXth International Conference Research for Furniture Industry was held with the cooperation of Poznan University of Life Sciences-Faculty of Wood Technology, Department of Furniture Design and Gazi University-Technology Faculty, Wood Products Industrial Engineering Department on 22–23 September 2022, in Poznań, Poland.

Up to the XXVIth annual conferences were held in Poland. The XXVIIth Conference was organized at Gazi University in Ankara with the participation of valuable scientists from 12 different countries in 2015. The XXVIIIth Conference was organized in Poland. The XXIXth International Conference Research for Furniture Industry was organized in 2019 in Ankara and focused on rapid changes in design, production, and marketing strategies in the Furniture Industry. This event will unite all industrial sectors parallel to the developing and changing world.

The conference aimed to enable academics, industry representatives, and students to share their experiences/knowledge in the field of engineering, machinery, manufacturing, management, material science, restoration, and protection and upholstery to meet the increasing consumer demands by diversifying; user-oriented, efficient use of natural resources, environmentally friendly approach, CAD/CAM/CAE, construction, design management, eco-design, ergonomics and anthropometrics, furniture industry, furniture mechanics and so on. The exchange of information and ideas should lead to the formulation of new directions for research activities in such areas and therefore support the furniture industry. An essential aspect of the Conference is to teach and acquaint young scientists (students and Ph.D. students) with the theoretical, experimental, and simulation methods used to explore these systems.

We want to thank the organizing committee's efforts and sincerity in providing employees with the preparation and success of the conference. We are grateful for supporting the Rectors of Poznań University of Life Sciences and Gazi University.

Prof. Dr. Jerzy Smardzewski
Prof. Dr. Cevdet Söğütlü

Modus of elasticity and flexural behavior of glulam beams reinforced with steel mesh in different mesh openings

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Keywords

wood material
lamination
reinforcement
support layers

Abstract

This study determined the modulus of elasticity and flexural strength properties of laminated wood elements reinforced with steel mesh with different mesh openings. Following the purpose of the study, 3- and 5-layer laminated elements were produced from scotch pine (*Pinus sylvestris* L.) wood material, which is widely used in the wood construction industry in Turkey. The 50, 70, and 90 mesh steel mesh used as the support layer is placed between each lamella and pressed with polyvinylacetate (PVAc-D_4) and polyurethane (PUR-D_4) adhesives. After the prepared test samples were kept for 3 weeks at 20°C temperature and 60 ±5% relative humidity for 3 weeks. Flexural strength and modulus of elasticity in flexural were determined according to the TS EN 408: 2010+A1 standard of the prepared test samples. Determined under static load from 4 points on the Zwick tester. Multiple analysis of variance (MANOVA) was carried out using the MSTAT-C software to determine the effect of the modulus of elasticity and flexural strength in the obtained flexural properties, the mesh opening of the support layer, and the adhesive type. When the differences within or between groups were significant with 0.05 margin of error; Achievement rankings were made using the Duncan test on the basis of the least significant difference.
As a result, in cases where flexural modulus and flexural strength properties are important, a lamination combination with a high level of success has been tried to be obtained.

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Introduction

Wood is an engineering material widely used in interior and exterior decoration applications due to its superior properties such as ease of processing, paintability, low energy consumption during processing, availability in various colors and patterns, low sound and heat permeability (Laboratory, 1974; Kopač and Šali, 2003; Aydın and Çolakoğlu, 2005; Söğütlü et al., 2016). Wood, in addition to its many superior

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properties, also has some disadvantages, such as being hygroscopic and heterogeneous and size limitation.

Today's technology has increased the durability of wood material and paved the way for the production of many new wood materials such as plywood, particleboard and other panel products. Wood material has been preferred as raw material in construction elements for the last 40 years and although it is used frequently, it is mostly in the form of timber obtained from tree trunks or wood pieces. Especially evergreen, coniferous, mature trees are seen as a source of structural timber. As with various other construction materials, wood material is available in different qualities (grades) and in many standardized features and sizes (Issa and Kmeid, 2005).

Elimination of the disadvantages of wood material such as heterogeneous structure, limited size possibilities and improvement of mechanical resistance properties can be reduced by lamination technology (Glulam = glue-laminated wood). Layered timber has been used since the 1800s. Research on this material started in the USA in the 1930s in Forest Products Laboratories (Dagher et al., 1996). Under prolonged load, wood will undergo viscoelastic creep, which requires a constant load that varies over time. When the load applied to the reinforced glulam beam changes over time, both the strength and stiffness of the beam will decrease. Once the prestress is applied, the distortion will become even more significant. Therefore, it is of great theoretical and engineering importance to understand the long-term mechanical performance of reinforced glulam beams and to clarify the effect of creep (Guo et al., 2021).

Reinforcement in glulam beams is a technique that provides greater advantages in both increased stiffness and strength, with structural members having higher mechanical performance. Reinforcement can be achieved using natural fibers or polymeric (artificial) fibers, which are usually bonded internally or externally to the laminate of the stretched region of the beams. It has been observed that reinforcement with metal elements, which can be applied to both the stretched and compressed regions of the glulam parts, is effective in reducing deflection and increasing the loading capacity (Luca and Marano, 2012). Metal material has been one of the most widely used materials for reinforcement since the 1960s. Steel bar, steel strip, steel or aluminum sheets, and steel knitted wire mesh are the best examples. Reinforcing wooden structures with steel material is both effective and cost-effective (Yang et al., 2016). The steel reinforced beams show that the behavior of reinforced beams is completely different from the non-reinforced one. The strengthening process changed the failure mode to dullly from fragile and increased the load carrying capacity of the beams (Issa and Kmeid, 2005). It has been determined that for simply reinforced beams, stiffness increased by 25.9%, the ultimate load increased by 48.1% and ductility increased by 43.8%. For reinforced and prestressed beams, stiffness increased by 37.9%, the ultimate load increased by 40.2% and ductility increased by 79.1% (Luca and Marano, 2012).

In a study that proposed that close-mounted steel rods could be used to reinforce glulam bamboo beams, a total of five glulam bamboo beams, one unreinforced and four reinforced, were constructed and tested to break under a four-point loading system, and the bending behavior was examined by comparing the differences. Experimental results showed that the load-bearing capacity and cross-sectional stiffness of the reinforced beams increased significantly compared to the unreinforced beam. It has also been found that steel bars mounted close to the surface can share the tensile stress of bamboo beams and work effectively during the loading process. Also, the plane section assumption of the cross-sectional stress distribution along the height is verified and an analytical model is proposed to predict the section stiffness of reinforced bamboo beams (Wei et al., 2015).

Load-displacement responses, ultimate capacities, ductility ratios, initial stiffness, energy dissipation capacities and fracture mechanisms of glued laminated beams were compared with the properties of solid beams. The use of reinforcing mesh on the laminated surfaces increased the ultimate load capacities of the tested beams. It was determined that the highest ultimate load capacities were observed in the tests of adhesive laminated beams, which were reinforced with polyurethane adhesive using steel wire reinforcement nets and produced using five laminated layers in the direction perpendicular to the lamination surface (Uzel et al., 2018).

The results of the study, which used one precast concrete, one post-tensioned concrete, one porous steel and one solid timber, were intriguing in the construction of four one-way parking garages. The resulting comparison shows that there is little difference in the energy of the structural systems used for car parks under material best practices. While solid timber is more suitable even in the worst-case scenario, it has been observed that it loses its advantageous position against its cement equivalent and high recycled content steel (Zeitz et al., 2019).

40 mm × 80 mm cross-section and 4.8 m span reinforced with bars made of steel reinforcement, rational zones for the location of reinforcement were determined in the stretched and compressed regions of the beams. It has been experimentally verified that the fracture of wood composite beams has a plastic structure and occurs only along normal sections. This excluded the possibility of brittle fracture from shear

stresses and ensured the operational reliability of the structures as a whole. It has been shown that the proposed rational reinforcement of wooden beams increases their bearing capacity by 175% and reduces bearing deformation by 85%. The study revealed the high efficiency of the application of the strengthening method in the roof beams and floors of the buildings (Lukin et al., 2021).

Compared to the unreinforced glulam beam, the long-term deflection of the reinforced glulam beam was even smaller. Under the constant loading level condition, the total stress value of the steel bars decreased by 17.5%, 13.6%, and 9.1%, and the ratio of long-term deflection of the beam mid-span to the total deflection was 26.9%. With the increase of the strengthening ratio, the stress loss of the steel bars decreased and the long-term deflection rate also decreased. When other conditions remained constant and the prestress level of the steel bars was 0 MPa, 30 MPa and 60 MPa, the total stress value of the steel bars decreased by 9.1%, 9.4% and 10.2%, respectively. The long-term deviation in the total deviation was determined as 20.6%, 26.1% and 64.9%, respectively. With the increase in the prestress value, the stress loss of the steel bars increased and the long-term deflection rate also increased (Guo et al., 2021).

As can be seen in the literature studies summarized above, wood is used for different purposes in different conditions. In order to achieve high success with smaller sized sections, wood is subjected to various processes and reinforced with different materials. The aim of this study is to determine the bending strength properties and elasticity properties in bending of glulam beams produced as 3 and 5 layers by placing a steel wire mesh with 50, 70 and 90 mesh pore openings between the layers obtained from Scotch pine (*Pinus sylvestris* L.).

Methods and materials

Materials

Wood

Scotch pine (*Pinus sylvestris* L.) used in the preparation of the test samples was selected according to criteria such as natural color uniformity, smoothness of fibers, absence of knots, absence of reaction wood, and the absence of fungal and insect damage.

Test samples formed into 7 and 4.2 mm lamellas, respectively, according to the 3 and 5-layered state, by wood saw and planer machines. The wood material, which became lamellae, was stacked and kept at 20 ±2°C temperature and 65 ±5% relative humidity until the equilibrium moisture content about 12%.

Stainless Steel Wire Mesh

Stainless steel wire meshes are used as braided in various places due to the continuity of their mechanical properties, their ability to preserve the aesthetic appearance and brightness on their surfaces for a long time, and they are not deformed even at high temperatures. They are preferred because they have a long life, do not require maintenance and have high mechanical resistance In this study, steel wires with 50, 70, and 90 mesh pore openings were used. The wire diameters are 0.18 mm, 0.12 mm, and 0.10 mm, respectively, and the pore spacing is 330 µm, 242 µm, and 180 µm (Fig. 1).

Table 1. Experimental plan

Adhesive type	Number of layers	Reinforcement
PUR-D_4	3	non-reinforcement
		50 mesh
		70 mesh
		90 mesh
	5	non-reinforcement
		50 mesh
		70 mesh
		90 mesh
PVAc-D_4	3	non-reinforcement
		50 mesh
		70 mesh
		90 mesh
	5	non-reinforcement
		50 mesh
		70 mesh
		90 mesh

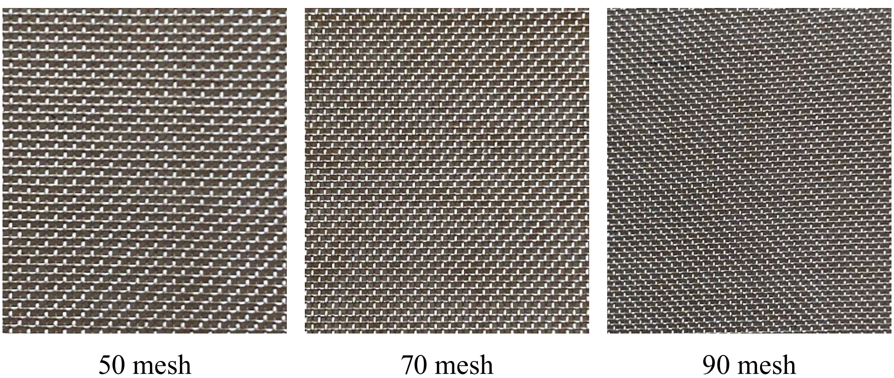

Fig. 1. Stainless steel wire mesh samples with different pore openings

Adhesives

The recommendations of the manufacturer (Klebreit) were followed for the application of polyvinylacetate (PVAc-D_4) and polyurethane (PUR-D_4) glue with the addition of hardener in the bonding of the layers. PVAc; viscosity at 20°C 13.000 ±2,000 mPas, color white, application amount 120–200 g/m^2, open time 6–10 min, press pressure 0.1–1 N/mm^2. PUR; viscosity of 8.000 ±1,000 MPa at 20°C, color yellowish brown, application amount of 100–200 g/m^2, open time 20–25 minutes, press pressure at least 0.6 N/mm^2 (Söğütlü, 2004).

Preparation of samples

The test samples were prepared with dimensions of 21 mm × 30 mm × 400 mm according to the TS EN 408: 2010+A1 standard. Polyvinylacetate adhesive (PVAc-D_4) and polyurethane adhesive (PUR-D_4) were applied to the 7 and 4.2 mm thick lamellas prepared by air-dried Scots pine (*Pinus sylvestris* L.) and reinforced with 50, 70 and 90 mesh steel wire mesh reinforcement and non-reinforced (control) experimental groups were formed.

Fig. 2. Preparation of the test samples

Two types of specimens were prepared, with and without reinforcement layer. Steel with 3 different mesh properties (50, 70, 90) was used between each layer of the samples consisting of 3 and 5 lamellas reinforced with the support layer. For each variable, 10 samples were prepared from both reinforced and non-reinforced experimental groups. While gluing the samples, 180–200 g/m^2 adhesive was applied with a brush on both surfaces of the lamellas and pressed under 1.2 N/mm^2 pressure. After waiting for at least 24 hours in the press, the samples were cut with a saw in dimensions of 21 mm × 30 mm × 400 mm (Fig. 3).

Fig. 3. Test samples after sizing

Conduct of experiments

Flexural strength and modulus of elasticity in flexural were determined according to the TS EN 408: 2010+A1 standard of the prepared test samples. Determined under static load from 4 points on the Zwick tester. The experimental setup is given in Fig. 4.

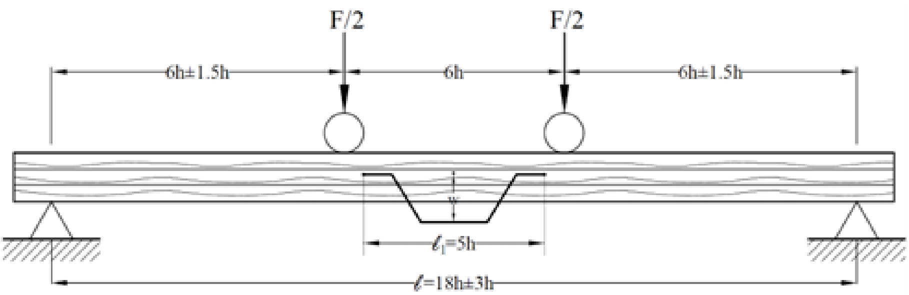

Fig. 4. The experimental setup

$$f_m = \frac{3F_{max} l_2}{bt^2}$$

f_m – flexural strength (N/mm²)
F_{max} – maximum load (N)
l_2 – 16 times the thickness (mm)
b – width (mm)
h – thickness (mm)

$$E_{m,g} = \frac{l^3 (F_2 - F_1)}{b_1 . h_1^3 (w_2 - w_1)} \left[\left(\frac{3a}{4l} \right) - \left(\frac{a}{l} \right)^3 \right]$$

E_m – modulus of elasticity (N/mm²)
l – length (mm)
b_1 – width (mm)
h_1 – thickness (mm)
a – distance between loading point and nearest support (mm)

$F_2 - F_1$ – increase in the load ratio on the right part of the load deformation curve (N)
$w_2 - w_1$ – the increase in deformation corresponding to $F_2 - F_1$ (mm).

The 4-point flexural strength (f_m) and modulus of elasticity ($E_{m,g}$) of the test specimens placed (Fig. 5) at a distance of 366 mm between the supports were calculated using the following equations.

Fig. 5. Performing flexural strength and modulus of elasticity test

Statistical analysis

The multiple analysis of variance (MANOVA) was carried out using the MSTAT-C package software to determine the effect of the modulus of elasticity and flexural strength in the obtained flexural properties, the mesh opening of the support layer, and the adhesive type. When the differences within or between groups were significant with 0.05 margin of error; achievement rankings were made using the Duncan test on the basis of the least significant difference (LSD). As a result, in cases where the modulus of elasticity and flexural strength properties are important, a lamination combination with a high level of success has been tried to be obtained.

Results and discussion

Flexural strength

Statistical values regarding the modulus of elasticity and flexural strength of non-reinforced beams made of 3 layers of lamellas of 7 mm thickness and reinforced beams made of 5 layers of 4.2 mm thick lamellas are given in Table 2.

Table 2. Modulus of elasticity, flexural strength, and standard deviation values (N/mm²)

Adhesive type	Number of layers	Reinforcement type	Number of samples	Flexural strength (N/mm²)	Modulus of elasticity (N/mm²)
PUR-D_4	3	non-reinforcement	10	103.2 ±4.8	19 629.5 ±1 862.0
		50 mesh	10	120.3 ±2.9	26 804.1 ±1 793.0
		70 mesh	10	107.6 ±1.8	22 310.4 ±1 823,6
		90 mesh	10	101.7 ±5.9	20 195.0 ±1 915.5
	5	non-reinforcement	10	79.6 ±9.0	15 359.9 ±1 041.2
		50 mesh	10	103.1 ±5.4	23 386.9 ±2 170.0
		70 mesh	10	104.7 ±2.0	19 367.1 ±1 729.4
		90 mesh	10	110.0 ±6.9	22 443.9 ±1 208.1
PVAc-D_4	3	non-reinforcement	10	96.0 ±2.7	18 730.2 ±1 900.5
		50 mesh	10	90.1 ±7.2	20 267.4 ±1 257.4
		70 mesh	10	107.9 ±8.0	22 310.4 ±1 823.6
		90 mesh	10	87.7 ±4.3	20 195.0 ±1 915.5
	5	non-reinforcement	10	93.6 ±5.6	16 178.3 ±1 071.1
		50 mesh	10	93.5 ±4.6	18 778.8 ±750.5
		70 mesh	10	95.3 ±3.0	19 367.1 ±1 729.4
		90 mesh	10	94.5 ±4.3	22 443.9 ±1 208.1

When the flexural strength values given in Table 3 are examined, it can be seen that there are differences according to the adhesive type, the number of layers and the characteristics of the reinforcement material. The results of the analysis of variance to determine the factor affecting the flexural strength are given in Table 3.

The difference between the groups in terms of the effects of the sources of variance on the flexural strength properties; adhesive types, numbers of layer, reinforcement type, adhesive types-numbers of layer, adhesive types-reinforcement type numbers of layer-pore openings binary interactions and adhesive types-numbers of layer- reinforcement type triple interaction level were statistically significant ($P \leq 0.05$).

Triple interaction Duncan results of adhesive type-number of layer-reinforcement type on flexural strength are given in Table 4.

Table 3. Analysis of variance results on flexural strength

Source of variance	Degrees of freedom	Sum of squares	Mean square	F value	$P \leq 0.05$
Adhesive type (A)	1	3 220.230	3 220.230	113.238	0.0000*
Number of layers (B)	1	1 014.049	1 014.049	35.659	0.0000*
Interaction (AB)	1	588.289	588.289	20.687	0.0000*
Reinforcement type (C)	3	2 652.834	884.278	31.095	0.0000*
Interaction (AC)	3	3 260.366	1 086.789	38.217	0.0000*
Interaction (BC)	3	2 320.004	773.335	27.194	0.0000*
Interaction (ABC)	3	1 833.480	611.160	21.491	0.0000*
Error	144	4 095.016	28.438		
Total	159	18 984.268			

*The difference is a significant level of 0.05.

Table 4. Triple interaction Duncan results of adhesive type-number of layers-reinforcement type on flexural strength (N/mm^2)

Reinforcement type	PUR-D_4				PVAc-D_4			
	3 layers		5 layers		3 layers		5 layers	
	$\bar{x}$	HG	$\bar{x}$	HG	$\bar{x}$	HG	$\bar{x}$	HG
Non-reinforcement	103.20	CD	77.88	H**	95.96	E	93.56	EF
50 mesh	120.30	A*	103.10	CD	90.08	FG	93.45	EF
70 mesh	107.60	BC	104.70	CD	107.90	BC	95.28	EF
90 mesh	101.70	D	110.00	B	87.67	G	94.48	EF

LSD ±5.339
$\bar{x}$ – arithmetic mean; HG – homogeneity group.
*The highest flexural strength. **The lowest flexural strength.

According to the results of the homogeneity test carried out to determine the importance of the triple interaction of adhesive types-number of layers-pore openings on the flexural strength properties. While the highest flexural strength (120.30 N/mm^2) was obtained in 50 mesh steel mesh reinforced beams with polyurethane adhesive, the lowest flexural strength (77.88 N/mm^2) was obtained in non-reinforced with polyurethane adhesive, produced as 5 layers. There is no statistical difference between 5-layer glued laminated wood beams bonded with PVAc-D_4. Additionally, there is no difference between the 3-layer non-reinforcement material bonded with PUR-D_4 and the 5-layer 50 mesh and 70 mesh reinforcement material (LSD ±5.34).

Modulus of elasticity

The results of the analysis of variance to determine the factor affecting the modulus of elasticity are given in Table 5.

Table 5. Analysis of variance results on modulus of elasticity

Source of variance	Degrees of freedom	Sum of squares	Mean square	F value	$P \leq 0.05$
Adhesive types (A)	1	204 453 427.879	204 453 427.879	82.9513	0.0000*
Number of layers (B)	1	200 843 606.456	200 843 606.456	81.4867	0.0000*
Interaction (AB)	1	846 327.390	846 327.390	0.3434	NS
Reinforcement type (C)	3	494 272 240.381	164 757 413.460	66.8457	0.0000*
Interaction (AC)	3	212 314 096.749	70 771 365.583	28.7135	0.0000*
Interaction (BC)	3	241 519 382.965	80 506 460.898	32.6633	0.0000*
Interaction (ABC)	3	54 665 131.811	18 221 710.604	7.3930	0.0001*
Error	144	354 922 737.069	2 464 741.230		
Total	159	1 763 836 950.430			

*The difference is a significant level of 0.05.

The difference between the groups in terms of the effects of the sources of variance on the flexural elasticity modulus; adhesive types, the number of layers, pore openings, adhesive types- reinforcement type number of layers-reinforcement type binary interaction levels were statistically significant ($P \leq 0.05$). However, adhesive types-number of layers' binary interaction levels were not statistically significant. Due to the anisotropic nature of the wood material, the difference between fiber length and wood elasticity modulus values; significantly affects the measured forces (Smardzewski et al., 2022).

Triple interaction Duncan results for adhesive types-number of layers-reinforcement types on the modulus of elasticity are given in Table 6.

Table 6. Homogeneity for the interaction of adhesive types-number of layers-reinforcement types on the modulus of elasticity (N/mm^2)

Reinforcement types	PUR-D_4				PVAc-D_4			
	3 layers		5 layers		3 layers		5 layers	
	$\bar{x}$	HG	$\bar{x}$	HG	$\bar{x}$	HG	$\bar{x}$	HG
Non-reinforcement	19 630	D	15 360	G**	18 730	DE	16 180	FG
50 mesh	26 800	A*	23 390	BC	20 270	D	18 780	DE
70 mesh	22 310	C	19 370	D	24 040	B	17 280	EF
90 mesh	20 190	D	22 440	C	17 440	EF	18 690	DE

LSD ±1387
$\bar{x}$ – arithmetic mean, HG – homogeneity group.
*The highest flexural strength.
**The lowest flexural strength.

According to the results of the homogeneity test carried out to determine the importance of the triple interaction of adhesive types-number of layers-reinforcement types on the modulus of elasticity; While the highest flexural strength (26800 N/mm²) was obtained in 50 mesh steel mesh reinforced beams with polyurethane adhesive produced as 3 layers, the lowest flexural strength (15360 N/mm²) was obtained in non-reinforced with polyurethane adhesive, produced as 5 layers (LSD ±1387).

The use of steel wire mesh between layers in the production of reinforced beams increases the flexural strength and modulus of elasticity in flexuring. In the use of 90 mesh steel-knitted wire mesh, 5-layer beams suffered more breakage than the 3-layer beams, regardless of the adhesive type. Additionally, it should be noted here that the glue line, which has a significant effect on the deformation of the beam between the layers, is damaged during bending (Smardzewski, 2019).

In terms of the effect on the flexural elasticity modulus, there is an increase of 60% in the reinforcements made with 50 steel mesh and polyurethane adhesive. There was a 31% increase in flexural strength of the same combination.

Conclusions

It is aimed to obtain glulam beams that will give high strength properties in terms of performance in the place of use by using steel wire mesh in different pore openings, different types of adhesives and different number of layers. For this purpose, between the layers of glulam beams, 50, 70, and 90 mesh steel wire mesh, which is considered more cost-effective, was used as reinforcement. Additionally, the lamella thicknesses of 4.2 mm (for 5 layers) and 7 mm (for 3 layers) were produced with the same final thickness of the glulam beams. The flexural strength and modulus of the elasticity properties of the reinforced glulam beams were determined. The obtained data were compared with beams produced non-reinforcement. Because of the experiment, non-reinforced glulam beams and reinforced glulam beams were evaluated statistically according to adhesive type, number of layers and pore openings.

In terms of adhesive type, the highest flexural strength value was obtained from polyurethane (PUR-D_4) glue, and the lowest flexural strength value was obtained from polyvinylacetate (PVAc-D_4) glue. Moreover, in terms of adhesive type, the highest modulus of elasticity properties was obtained from PUR-D_4 glue and the lowest modulus of elasticity properties was obtained from PVAc-D_4 glue.

In terms of adhesive type, PUR-D_4 glue gave high results for the highest flexural strength and modulus of elasticity, while PVAc-D_4 glue gave low results. This result can be interpreted as that polyurethane glue establishes a stronger chemical bond between the lamellae compared to polyvinylacetate glue.

The highest flexural strength and modulus of elasticity values were obtained from 3 layers, and the lowest flexural strength value was obtained from 5 layers.

In terms of pore openings, the highest flexural strength value was obtained from 70 mesh, and the lowest flexural strength value was obtained from non-reinforcement glulam beam. Again, in terms of pore openings, the highest modulus of elasticity properties was obtained from 50 mesh, and the lowest modulus of elasticity was obtained from non-reinforcement glulam beam. In line with the data obtained, it can be interpreted that as the pore opening increases, the flexural strength decreases. Here, it can be interpreted that porous reinforcement materials may be preferred instead of plate-shaped reinforcement material to be used between layers. Simultaneously, the use of 90 mesh can be recommended in cases where elasticity is desired, while the use of 50 mesh can be recommended in applications that require rigidity.

As a result, it is predicted that satisfying results can be obtained by diversifying adhesives with different wood species in the construction sector, and by experimenting with different reinforcements, variable number of layers and sequences. Additionally, the preliminary idea was been formulated that materials with a porous structure as reinforcement will increase the healing effect more.

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References

Aydın, İ., Çolakoğlu, G. (2005). Effects of surface inactivation, high temperature drying and preservative treatment on surface roughness and colour of alder and beech wood. Applied Surface Science, 252 (2), 430–440. https://doi.org/10.1016/j.apsusc.2005.01.022

Dagher, H.J., Kimball, T.E., Shaler, S.M., Abdel-Magid, B. (1996). Effect of FRP reinforcement on low grade eastern hemlock glulams. National Conference on Wood Transportation Structures (pp. 215–207). Madison, WI. https://intrans.iastate.edu/app/uploads/2018/08/daghe96b.pdf

Guo, N., Ren, J., Li, L., Zhao, Y., Wu, M. (2021). Long-term loading test of reinforced glulam beam. Journal of Renewable Materials, 9(12), 183–201. https://doi.org/10.32604/jrm.2021.015756

Issa, C.A., Kmeid, Z. (2005). Advanced wood enineering: glulam beams. Construction and Building Materials, 19(2), 99–106. https://doi.org/10.1016/j.conbuildmat.2004.05.013
Kopač, J., Šali, S. (2003). Wood: An important material in manufacturing technology. Journal of Materials Processing Technology, 133(1–2), 134–142. https://doi.org/10.1016/S0924-0136(02)00217-0
Laboratory, F.P. (1974). Wood Handbook: Wood As An Engineering Material. U. S. Department of Agriculture Forest Products Laboratory.
Luca, V.D., Marano, C. (2012). Prestressed glulam timbers reinforced with steel bars. Construction and Building Materials, 30, 206–217. https://doi.org/10.1016/j.conbuildmat.2011.11.016
Lukin, M., Prusov, E., Roshchina, S., Karelina, M., Vatin, N. (2021). Multi-span composite timber beams with rational steel reinforcements. Buildings, 1(2), 46. https://doi.org/10.3390/buildings11020046
Smardzewski, J. (2019). Experimental and numerical analysis of wooden sandwich panels with an auxetic core and oval cells. Materials and Design, 183:108159. 10.1016/j.matdes.2019.108159
Smardzewski, J., Majnusz, M., Murlak, K. (2022). Bending and energy absorption performance of novel openwork. European Journal of Wood and Wood Products, 80, 515–528. https://doi.org/10.1007/s00107-022-01795-6
Söğütlü, C. (2004). The posibilities of using some native wood species in the construction of kundekari. Doctoral Thesis, Ankara: Gazi University, Institute of Science.
Söğütlü, C., Döngel, N. (2007). Tensile shear strengths of some local woods bonded with polyvinyl acetate and polyurethane adhesives. Journal of Polytechnic, 10(3), 287–293. 10.2339/2007.10.3.287-293
Söğütlü, C., Nzokou, P., Koç, İ., Tutgun, R., Döngel, N. (2016). The effects of surface roughness on varnish adhesion strength of wood materials. Journal of Coatings Technology and Research, 13, 863–870. DOI:10.1007/s11998-016-9805-5
Uzel, M., Togay, A., Anıl, Ö., Söğütlü, C. (2018). Experimental investigation of flexural behavior of glulam beams reinforced with different bonding surface materials. Construction and Building Materials, 158, 149–163.
Wei, Y., Zhou, M.Q., Chen, D.J. (2015). Flexural behaviour of glulam bamboo beams reinforced with near-surface mounted steel bars. Materials Research Innovations, 19, 98–103. https://doi.org/10.1179/1432891715Z.0000000001377
Yang, H., Liu, W., Lu, W., Zhu, S., Geng, Q. (2016). Flexural behavior of FRP and steel reinforced glulam beams: experimental and theoretical evaluation. Construction and Building Materials, 106, 550–563. https://doi.org/10.1016/j.conbuildmat.2015.12.135
Zeitz, A., Griffin, C., Dusicka, P. (2019). Comparing the embodied carbon and energy of a mass timber structure system to typical steel and concrete alternatives for parking. Energy & Buildings, 199, 126–133. https://doi.org/10.1016/j.enbuild.2019.06.047

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Investigating the usability of terrestrial animal and fish bones in the production of polymer composites

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Keywords

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Abstract

Increasing raw material requirements with developing technologies leads to the search for new materials. This study investigated the usability of terrestrial animal and fish bones, which are considered waste, in producing polymer composites. In this context, composite panels were produced by mixing the materials as chip form into high-density polyethylene (HDPE) polymer homogeneously at the rate of 10–30–50% by weight. Some of the physical and mechanical properties of produced panels were investigated and compared with the results of some referenced research that studied wood-plastic composites (WPC). The results of the study provided important insight into the usability of terrestrial animal and fish bones in polymer composite production. As a result, it can be concluded that the panel produced with terrestrial animal and fish bone may be suitable to use in case of water resistance required but in non-load bearing conditions.

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Introduction

Due to increasing environmental concerns, composite materials have attracted great attention in recent years. In addition to offering superior properties compared to its own components, it enables more efficient use of potential raw materials. Wood-plastic composite (WPC) is one of the well-known examples of them. WPC has continued to develop over the last 50 years and the application areas of WPC are constantly expanding for both structural and non-structural applications such as decking materials, fences, window and door frames, furniture, siding, timber, playground equipment, docks, bridges, and traverses (Smith and Wolcott, 2006; Schwarzkopf and Burnard, 2016). WPC has mainly produced by the thermoplastic polymers (polyethylene (PE)), polypropylene (PP), polyvinyl chloride (PVC) and polystyrene (PS) and the biomass particles and fibers from forestry and agricultural wastes (wood, bamboo, straw, stalk, husk and bast) (Deka and Maji, 2011; Adhikary et al., 2011).

Like forestry and agricultural wastes, a considerable amount of terrestrial animal and fish residue is produced in the world every year. Seafood production has increased every year and reached 177 million 834 thousand tons in 2019 in the world (FAO, 2021). An increase in daily seafood production causes many processing residues that must be disposed of. Evaluation of fish waste is a subject on which researches are concentrated. In order to evaluate these residues, many different methods are tried together with technological development. The residues are used in pharmaceuticals, cosmetics, feed and many other industrial areas by undergoing various processes. Globally, 60% of the fish caught is processed. This causes around 27.85 million tons of residues (Thirukumaran et al., 2022). Approximately 10–15% of the total mass of fish is bone (Toppe et al., 2006) and 15.3% ±4.6% of this bone is in the backbone and 21.5% ±4.3% is in the head. Fish bone constitutes the most important part of seafood residues (Thirukumaran et al., 2022; Toppe et al., 2006). Although fish bones are used in gelatin production, medical and dental fields or as fish meal and biofertilizer (Thirukumaran et al., 2022; Geahchan et al., 2022; Mutalipassi et al., 2021; Phadke et al., 2021; Ucak et al., 2021; V´azquez et al., 2021), these are applications that require extensive and expensive processes and cannot be met by every enterprise. Therefore, more research should be done on the methods of easy evaluation of fish bones in different areas.

To meet the meat consumption in the world, the amount of terrestrial animal production is increasing every year. Approximately 337.2 million tons of meat were produced globally in 2020 (Destatis, 2022). The most common solid waste of slaughterhouse is bone (Mengistu and Reshad, 2022). 30.4% of the residues from a cattle are bone. In worldwide meat production, approximately 0.13 billion tons of bone is produced as waste, annually (Mengistu and Reshad, 2022). Structure of bovine bones are same as fish bone. Animal bone consists of hydroxyapatite, has good thermal stability, beside filled with inorganic minerals such calcium and phosphorus, and has a porous crystal structure (Mengistu and Reshad, 2022). Beef bones can be evaluated as bone meal and bone oil moreover, glue and gelatin are obtained from them. Obadiah et al. (2012), used bones as a source of heterogeneous catalysts by carbonizing them. In addition, filters, light-sensitive photographs and x-ray films are produced from bones with undergoing different processes.

In this study, it is aimed to investigate the possibility of using fish and terrestrial animal bones as a filling material in plastic composites which is in a very different field than food, agriculture and medicine.

Methods and materials

Materials

Terrestrial animal and fish bone flour with a particle size of 20 to 40 mesh was used as a filling material and the powder form of high-density polyethylene (HDPE) (Ucar Plastic, Izmir, Türkiye) was used as polymer material, which were provided by commercial suppliers. The polymer's density and melt flow index (MFI) were 0.965 g.cm^3 and 5.5 g/10 min (190°C/2.16 kg), respectively. The experimental design that consist of mixing ratios of terrestrial animal and fish bone content and HDPE is given in Table 1.

Table 1. The content of filling flour and HDPE in the mixture

Terrastial animal bone flour		
Groups	Filling flour (%)	HDPE (%)
TABPC0	0	100
TABPC1	10	90
TABPC2	30	70
TABPC3	50	50
Fish bone flour		
FBPC0	0	100
FBPC1	10	90
FBPC2	30	70
FBPC3	50	50

Preparation of composites

The filling flours were dried to under 2% of moisture content. The filling flour and polymer were first pre-mixed with a mechanical blender (1200 rev.min-1) and then, homogenized with a rotary drum blender (30 to 40 rev.min-1 for 5 min). The prepared mixture was laid between two aluminum caul plate and pressed with a flat table hot-press machine (Cemil Usta SSP 125, Istanbul, Türkiye) for 15 min under a pressure of 2.3–2.5 N/mm^2 at 170°C. To prevent sticking of the mixture to the plates, wax paper was used in both sides. At the end of pressing time the panels were kept in the switched off hot press for cooling. The panels dimension were 500 × 500 × 4 mm.

Three panel were produced for each group. The target density of the panels was 1.0 g/cm^3. The panels were conditioned according to ASTM D618-21 (2021).

Testing procedures

Density, water absorption (WA) and volumetric swelling (VS) after 1 day, 3 days and 60 days water-soaking test, surface roughness test and glossiness tests were carried out to determine as physical properties of the produced panels. In addition, modulus of elasticity in bending (MOE), modulus of rupture (MOR), tensile strength were carried out to evaluate as mechanical properties of the panels. Mechanical tests were conducted with a universal testing machine (Marestek, Istanbul, Türkiye). Ten replications were tested for each group. Testing procedures were carried out according to related standarts that are given in Table 2.

Table 2. The standards used for some of technological properties in the study

Test	Standard
Density	ASTM D792 (2013)
Water absorption and thickness swelling	ASTM D570-98 (2018)
Surface roughness	DIN 4768 (1990)
Glossiness	Measured with Glossmeter at 20–60–85 degree
Modulus of elasticity in bending (MOE)	ASTM D790-17 (2017)
Modulus of rupture (MOR)	ASTM D790-17 (2017)
Tensile strength	ASTM D638-14 (2014)

Statistical analysis

The test results were evaluated statistically according to the analysis of variance (ANOVA) (SPSS, IBM Corporation, Version 22, Armonk, NY, USA).

Results and discussion

Density

The effect of terrestrial animal and fish bone flour content changes on the density of produced panels are shown in Table 3.

According to the table, values varied between 0.97 to 1.14 g/cm^3 for the panel that produced with terrestrial animal bone and 0.94 to 1.12 g/cm^3 for the fish bone. As can be seen from the table, density increases as both terrestrial animal and fish bone additive ratio increase.

Table 3. Density values

Sample		Density (g/cm^3)
Control (PE)		0.96
Terrestial animal bone (%)	10	0.97
	30	1.05
	50	1.14
Fish bone (%)	10	0.94
	30	1.03
	50	1.12

Volumetric swelling (VS) and water absorption (WA)

The results related to effect of terrestrial animal and fish bone content changes on the VS and WA were investigated throughout 60 days test were given in Table 4.

Table 4. Results of volumetric swelling and water absorption (%)

Sample		Volumetric swelling			Water absorption		
		1 day	3 days	60 days	1 day	3 days	60 days
Control (PE)		0.00	0.00	0.56	0.13	0.30	1.07
Terrestial animal bone (%)	10	0.30	0.73	3.22	0.33	0.81	4.38
	30	0.65	0.65	3.66	0.65	1.40	4.77
	50	2.40	2.84	4.85	1.55	2.56	5.30
Fish bone (%)	10	0.87	1.01	0.99	0.38	0.55	5.05
	30	1.10	1.28	2.73	0.25	0.89	5.54
	50	3.82	4.45	3.45	2.09	3.35	6.07

It can be understood from the table that VS and WA values increase depend on both terrestrial animal and fish bone additive ratio and exposure time increased. As is well known, the polymers are hydrophobic and not effected by water molecules as can be seen control sample that was influenced very limitedly. The highest VS and WA values obtained from the panels that produced with 50% terrestrial animal and fish bone flour content. However, it is seen that values are very low when compared with some research that studied with wood-plastic composites (WPC) (Gezer et al., 2016; Durmaz, 2021).

Surface roughness (μm)

The results of surface roughness values were given in Table 5. In general, surface roughness values increase depend on both terrestrial animal and fish bone content ratio increase. The highest surface roughness values were obtained as 4.83 µm from the panel produced with 50% fish bone.

Table 5. Results of surface roughness

Sample		Mean			Standard deviation			Coefficient of variation (Cov)		
		Ra	Rz	Rq	Ra	Rz	Rq	Ra	Rz	Rq
Control (PE)		3.24	19.81	4.01	0.52	2.40	0.46	16.16	12.12	11.51
Terrastial animal bone (%)	10	3.09	18.75	4.07	0.67	3.56	0.74	21.79	18.99	18.12
	30	4.35	24.72	5.43	0.79	3.53	0.63	18.21	14.30	11.52
	50	4.24	25.15	5.52	0.41	2.49	0.44	9.78	9.91	8.05
Fish bone (%)	10	4.05	21.93	5.23	0.53	3.15	0.73	13.11	14.36	13.94
	30	4.17	23.32	5.26	0.70	4.37	0.84	16.69	18.72	16.03
	50	4.83	30.81	6.40	0.81	3.20	1.50	16.86	10.39	23.37

The surface roughness is related with particle size of the content. It is thought that the reason for the increasing surface roughness is the particle size of the used as bone flour in this study. Therefore, the surface roughness may reduced by using smaller particle size of bone additive in the content of the panels.

Glossiness (Gu)

The results of glossiness test values at 60° incidence angle were presented in Table 6. Glossiness is an important factor for the aesthetic and appearance of the material. The lowest glossiness value was obtained from control sample while the highest values were obtained from the panel produced with 10% terrestrial animal and fish bone content.

Table 6. Results of glossiness

Sample		Mean (60°)	Standard deviation	Coefficient of variation (Cov)
Control (PE)		3.76	0.49	12.91
Terrastial animal bone (%)	10	4.78	0.50	10.39
	30	4.29	0.67	15.58
	50	4.50	1.00	22.24
Fish bone (%)	10	4.76	1.29	27.17
	30	4.68	1.57	33.44
	50	4.33	1.41	32.52

Modulus of rupture (MOR)

The results of modulus of rupture test were given in Table 7. The highest value was obtained from control group with 48.45 N/mm^2 while the lowest value was obtained with 12.21 N/mm^2 from the panel produced with 50% fish bone content.

Table 7. Results of modulus of rupture (MOR) (N/mm^2)

Sample		Mean	Standard deviation	Coefficient of variation (Cov)
Control (PE)		48.45	2.09	4.31
Terrastial animal bone (%)	10	36.49	2.88	7.89
	30	17.57	3.13	17.83
	50	13.79	2.00	14.53
Fish bone (%)	10	37.80	2.08	5.51
	30	21.27	3.76	17.70
	50	12.21	1.30	10.60

It can be seen from the table that values were decreased as both terrestrial animal and fish bone content increased. In comparison to similar research in the literature that studied with WPC (Durmaz, 2021; Avci, 2012; Avci et al., 2014) MOR values are very low.

Modulus of elasticity (MOE)

The results of MOE test were presented in Table 8. The highest value was obtained from control group with 1683.98 N/mm^2 while the lowest value was obtained with 1381.4 N/mm^2 from the panel produced with 50% terrestrial animal bone content.

Table 8. Results of modulus of elasticity (MOE) (N/mm^2)

Sample		Mean	Standard deviation	Coefficient of variation (Cov)
Control (PE)		1 683.98	127.29	7.56
Terrastial animal bone (%)	10	1 529.09	168.30	11.01
	30	1 413.11	292.68	20.71
	50	1 381.40	176.68	12.79
Fish bone (%)	10	1 561.44	101.89	6.53
	30	1 594.98	75.73	4.75
	50	1 401.72	243.30	17.36

In general, values were decreased as both terrestrial animal and fish bone content increased. In comparison to similar research in the literature that studied with WPC (Durmaz, 2021; Avci, 2012; Avci et al., 2014) MOE values are very low.

Tensile strength

The results of tensile strength test were shown in Table 9. The highest value was obtained from control group with 26.95 N/mm^2 while the lowest value was obtained with 2.8 N/mm^2 from the panel produced with 50% fish bone content.

Table 9. Results of tensile strength (N/mm^2)

Sample		Mean	Standard deviation	Coefficient of variation (Cov)
Control (PE)		26.95	5.43	20.15
Terrastial animal bone (%)	10	10.43	2.20	21.08
	30	6.59	1.50	22.72
	50	5.25	0.71	13.58
Fish bone (%)	10	11.66	2.95	25.32
	30	6.06	0.99	16.40
	50	2.80	0.53	19.08

According to the table, it can be said that a considerable decrease were realized in tensile strength of the materials. Additionally, values were decreased as both terrestrial animal and fish bone content increased. As a reason, it is thought that there were not realized enough strong bond structure between polymer and terrestrial animal and fish bone flour. In comparison to similar research in the literature that studied with WPC (Durmaz, 2021; Avci, 2012; Avci et al., 2014) MOE values are very low.

Conclusions

This study was aimed to investigate usability of terrestrial animal and fish bone waste in production of polymer composites. For this purpose, composite boards were produced by mixing the materials as chip form into high density polyethylene (HDPE) polymer homogeneously at the rate of 10–30–50% by weight. Density, VS and WA, surface roughness and glossiness properties were investigated as physical properties, MOR, MOE and tensile strength properties were investigated as mechanical properties of the produced panels.

According to the results, despite VS and WA test samples exposure to water for 60 days, results were given considerable lower results in comparison with some of referenced WPC values. Accordingly, it can be said that the panels may suitable to use in application which required water resistance. For the surface roughness and glossiness, as the additive ratio of both terrestrial and fish bone content increased, values for surface roughness increased and glossiness were decreased. In case of required low surface roughness and high glossiness values, particle size may use in smaller sizes that used in this study.

On the side of mechanical properties, in general, MOR and MOE values were considerable decreased as additive ratio of the terrestrial animal and fish bone increased within the mixtures. Similar situation were realized in tensile strength values as well. When the results were compared with some referenced WPC results, it was seen that MOR and MOE values are very low especially in tensile strength.

As a result of this study, it can be said that the produced panels may be suitable to use for the area of water resistance but non-load bearing required. More research may be carried out to develop mechanical properties by using coupling agents and reinforced materials.

References

Adhikary, K.B., Park, C.B., Islam, M.R., Rizvi, G.M. (2011). Effects of lubricant content on extrusion processing and mechanical properties of wood flour-high-density polyethylene composites. Journal of Thermoplastic Composite Materials, 24(2), 155–171. https://doi.org/10.1177/0892705710388590

ASTM D570-98, 2018. Standard test methods for water absorption of plastics. https://asrecomposite.com/wp-content/uploads/2021/07/ASTM-D-570-19982018.pdf

ASTM D638-14, 2014. Standard test methods for tensile properties of plastics. https://borgoltz.aoe.vt.edu/aoe3054/manual/expt5/D638.38935.pdf

ASTM D790-17, 2017. Standard test methods for flexural properties of unreinforced and reinforced plastics and electrical insulating materials. https://asrecomposite.com/wp-content/uploads/2021/07/ASTM-D-790-2017.pdf

ASTM D792, 2013. Standard test methods for density and specific gravity (relative density) of plastics by displacement. https://asrecomposite.com/wp-content/uploads/2021/07/ASTM-D792-2020.pdf

Avci, E. (2012). Investigations on usage performance of wood plastic composites. Ph.D. thesis, Institutıon of Science, Istanbul University, Istanbul, Turkiye.

Avci, E., Candan, Z., Gonultas, O. (2014). Performance properties of biocomposites from renewable natural resource. Journal of Composite Materials, 48(26), 3237–3242. https://doi.org/10.1177/0021998313508595

Deka, B.K., Maji, T.K. (2011). Study on the properties of nanocomposite based on high density polyethylene, polypropylene, polyvinyl chloride and wood. Composites Part A: Applied Science and Manufacturing, 42(6), 686–693. https://doi.org/10.1016/j.compositesa.2011.02.009

Destatis (2022). Global animal farming, meat production and meat consumption. International Statistics. Statistisches Bundesamt, Gustav-Stresemann-Ring 11, 65189 Wiesbaden, Germany. https://www.destatis.de/EN/Themes/Countries-Regions/International-Statistics/Data-Topic/AgricultureForestryFisheries/livestock_meat.html

DIN 4768. Determination of surface roughness values of the parameters Ra, Rz, Rmax by means of electrical contact (stylus) instruments; terminology, measuring conditions., Berlin, 1990. https://global.ihs.com/doc_detail.cfm?document_name=DIN%20 4768&item_s_key=00120852

Durmaz, S. (2021). Effect of wood flour content on the properties of flat pressed wood plastic composites. Wood Research, 67(2), 302–310. 10.37763/wr.1336-4561/67.2.302310

FAO (2021). Fishery and aquaculture statistics 2019, FAO Statistic Yearbook. Roma. https://doi.org/10.4060/cb7874t

Geahchan, S., Baharlouei, P., Rahman, A. (2022). Marine collagen: a promising biomaterial for wound healing, skin anti-aging, and bone regeneration. Marine Drugs, 20(1), 61. https://doi.org/10.3390/md20010061

Gezer, E.D., Akbas, S., Tufan, M., Temiz, A. (2016). Properties of wood plastic composites made of recycled HDPE and remediated wood flour from CCA/CCB treated wood removed from service. 47 th IRG Annual Meeting, 15–19 May, Lisbon, Portugal. https://www.researchgate.net/publication/303411681_Properties_of_Wood_Plastic_Composites_Made_of_Recycled_HDPE_and_Remediated_Wood_Flour_from_CCACCB_Treated_Wood_Removed_from_Service

Mengistu, T.G., Reshad, A.S. (2022). Synthesis and characterization of a heterogeneous catalyst from a mixture of waste animal teeth and bone for castor seed oil biodiesel production. Heliyon, 8, e09724. https://doi.org/10.1016/j.heliyon.2022.e09724

Mutalipassi, M., Esposito, R., Ruocco, N., Viel, T., Costantini, M., Zupo, V. (2021). Bioactive compounds of nutraceutical value from fishery and aquaculture discards. Foods, 10. https://doi.org/10.3390/foods10071495

Obadiah, A., Swaroopa, G.A., Kumar, S.V., Jeganathan, K.R., Ramasubbu, A. (2012). Biodiesel production from palm oil using calcined waste animal bone as catalyst. Bioresource Technology, 116, 512–516. https://doi.org/10.1016/j.biortech.2012.03.112

Phadke, G.G., Rathod, N.B., Ozogul, F., Elavarasan, K., Karthikeyan, M., Shin, K.-H., Kim, S.-K. (2021). Exploiting of secondary raw materials from fish processing industry as a source of bioactive peptide-rich protein hydrolysates. Marine Drugs, 19(9), 480. https://doi.org/10.3390/md19090480

Schwarzkopf, M.J., Burnard, M.D. (2016). Wood-plastic composites: Performance and environmental impacts. In: A. Kutnar, S. Muthu (eds.), Environmental impacts of traditional and innovative forest-based bioproducts. Environmental Footprints and Eco-design of Products and Processes. Springer, Singapore. https://doi.org/10.1007/978-981-10-0655-5_2

Smith, P.M., Wolcott, M.P. (2006). Opportunities for wood/natural fiber-plastic composites in residential and industrial applications. Forest Products Journal, 56(3), 4–11. https://www.researchgate.net/publication/235979210_Opportunities_for_woodnatural_fiber-plastic_composites_in_residential_and_industrial_applications

Thirukumaran, R., Priya, V.K.A., Krishnamoorthy, S., Ramakrishnan, P., Moses, J.A., Anandharamakrishnan, C. (2022). Resource recovery from fish waste: Prospects and the usage of intensified extraction technologies. Chemosphere 299, 134361. https://doi.org/10.1016/j.chemosphere.2022.134361

Toppe, J., Albrektsen, S., Hope, B., Aksnes, A. (2006). Chemical composition, mineral content and amino acid and lipid profiles in bones from various fish species. Comparative Biochemistry and Physiology Part B 146, 395–401. https://doi.org/10.1016/j.cbpb.2006.11.020

Ucak, I., Afreen, M., Montesano, D., Carrillo, C., Tomasevic, I., Simal-Gandara, J., Barba, F.J. (2021). Functional and bioactive Properties of peptides Derived from marine side streams. Marine Drugs, 19(2), 71. https://doi.org/10.3390/md19020071

V´azquez, J.A., Hermida-Merino, C., Hermida-Merino, D., Pi˜neiro, M.M., Johansen, J., Sotelo, C.G., P´erez-Martín, R.I., Valcarcel, J. (2021). Characterization of gelatin and hydrolysates from valorization of farmed salmon skin by-products. Polymers, 13, 2828. https://doi.org/10.3390/polym13162828

https://doi.org/10.17306/mk.978-83-67112-51-2.2

The effect of accelerated UV aging process on total color change after the varnishing process of 3D-printed wood composite material

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Keywords

3D printer
wood-plastic composite
UV

Abstract

This study investigated the effect of UV aging applied to the wood composite material produced by a 3D printer after varnish application on the total color change. For this purpose, water-based varnish and teak oil were applied to the wood composite material produced with wood-added filaments with 30% and 60% occupancy rates in a 3D printer, and on the same sizes of solid Oriental beech (*Fagus orientalis* Lipsky.) for comparison purposes. Then, the samples were subjected to rapid aging in a UV device for 24 hours, 48 hours, and 72 hours, and the color changes that occurred were analyzed. Obtained data were compared statistically with the MSTAT-C program. The type of material, UV exposure time, and type of surface protection material affect the total color change. While high occupancy rate and UV application time are effective in increasing total color change, teak oil is less effective in color change than water-based varnish.

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Introduction

The open-air effect is an important risk factor for tree material. This outdoor effect, called “Weathering” is a chemical and physical change in color on the wood material surface with the effect of light (UV, IR), humidity (rain, snow, humidity, dew), mechanical forces (wind, sand, dirt) and temperature causes some changes (Ekinci, 2011).

One of the main reasons why the color change in wood material is so important is that the color change determines the value of the material in the place of use. For this reason, protective surface treatments are applied to the wood material surface in order to reduce or completely eliminate color changes.

Before the surface treatments to be applied to the wood material, sanding is done to provide stability on the material surface finishing and this process is also effective on the color change. Thermal treatment can be applied to reduce the color change caused by the sanding process applied to the material surface. As a result of applying thermal processing instead of sandpaper, sensitivity in color differences decreases (Bekhta et al., 2022). Increasing the moisture content of the materials to be treated on the surface also helps to reduce the color change value. In a study, the humidity of the material to be varnished was determined as 8%, 10% and 12%, and water-based varnish was applied to the materials. Looking at the results of the study, it was determined that the least color change occurred in materials with 12% moisture content (Budakçı et al., 2012). Various methods are used to keep the amount of color change caused by finishing applied to the wood material surface. One of them is the addition of nanoparticles into the varnish. However, adding nanoparticles into the varnish to be used does not always give the desired results. Depending on the chemical structure of the nanoparticle used and the reactions that occur as a result of the interaction of this structure with the varnish, the color change may decrease or increase. While the increase in the color change was found to be high in the samples varnished with the varnishes to which the researchers added nano graphene, the increase in the color change was found to be low in another study using aluminum oxide and titanium dioxide (Aksu et al., 2022; Pelit and Korkmaz, 2019).

With proliferation the use of harmless products to nature, people and the environment in every field in recent years, studies are carried out to use natural and environmentally friendly alternatives instead of chemicals used in the woodworking industry. For this reason, the chemicals used especially in surface treatments have started to leave their place to natural alternatives. Alternatives such as tannin and valex are also used to eliminate this feature of the wood material, which has a structure affected by weather conditions like other polymers due to being an organic polymer. The use of tannin and valex, which are UV repellent, allows reductions in color change to compete with synthetic UV repellents (Tomak et al., 2018).

Varnish types have an effect on color change. When the effect of synthetic, cellulosic and water-based varnishes, which are widely used in the furniture industry, on the color change has been investigated, it was seen that the highest color change was in the materials varnished with synthetic varnish (Aykaç and Sofuoğlu, 2021).

With the development of the paint industry, it is seen that the color change in UV paint and varnish systems, which have been applied on wood materials in recent years, is directly proportional to the number of layers applied. As the number of layers increases, the total color change also increases (Gürleyen, 2021).

It is thought that the color change, which significantly affects the surface appearance of the wood material, is also an important factor for the wood-added filaments.

3D printers, one of the additive manufacturing methods that entered our lives with Industry 4.0, have also started to be used in the furniture industry. In the 3D printer technology, where filaments obtained from materials such as ABS and PLA are used extensively, wood-added PLA filaments are also used, which give the feeling of wood both in appearance and texture.

In the literature review, there was no study on the total color change that occurs as a result of varnishing the filaments. In this study, test samples printed with wood-added filaments with 2 different filling ratios and the total color change observed after 2 different varnish applications on beech wood were examined.

Methods and materials

Materials

Wood-added filaments to be printed from a 3D printer and teak oil and water-based varnish were used to make the top surface execution. The technical properties of the filament are given in table 1.

Table 1. Technical specifications of wood-added filament

Filament thickness	1.75 mm (0.01 mm precision)
Press temperature	190–220°C
Table temperature	0–80°C

Method

A total of 30 samples with the size of 100 × 100 × 8 mm were printed. The nozzle temperature and the printing speed of the samples were 200°C and 70 mm. While the fill rate of 15 samples was 30%, the fill rate of the other 15 samples was 60%. The material was printed with an open system 3D printer using wood-added PLA filament. The printing parameters of the 3D printer are given in Table 2.

The produced samples were kept in the air-conditioning cabinet adjusted to 20°C temperature and 65% relative humidity conditions until they reached a constant weight and became air-dry moisture content (12%). In order to compare the samples printed from the filament with the wood material, 15 test samples were prepared with a size of 100 × 100 ×8 mm, obtained from the beech (*Fagus orientalis* L.) wood, which is widely used in the woodworking industry.

Table 2. Printer parameters

Printer material	Wood added PLA
Layer height (mm)	0.3
Nozzle diameter (mm)	0.4
Filling ratio (%)	50
Printer nozzle temperature	200°C
Filament diameter (mm)	1.75
Fill pattern	linear

Each test sample was sanded with 180-grit sandpaper before varnishing and the amounts to be used in the surface treatment were prepared by taking into account the company's recommendations and applied to the sample surfaces.

The test samples were kept in a rapid aging (UV) device for 72 hours in accordance with TS EN ISO 4892-2 principles (TS EN ISO 4892-2, 2013). The irradiation intensity was selected as 340 mm under device operating conditions and the samples were positioned 100 mm away from the beam source. Each test sample was measured with a color-measuring device with a fixed reference point before being placed in the artificial aging device. The last measurement of the test samples, which were measured in 24-hour periods, was made at the 72nd hour and the aging process was terminated.

CIEL*a*b* color measurement system was used to measure the total color of the test samples. Color differences determined according to L* (color brightness), a* (red hue), b* (yellow hue) color coordinates and their locations form the basis of the CIEL*a*b* system (Söğütlü and Sönmez, 2006). The representation of the color areas in the CIEL color system is given in Fig. 1.

Fig. 1. CIELAB Color Space

The a, b and L values were used to calculate the total color change and the following equation was used.

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \quad (1)$$

A low total color change value indicates that the color has not changed or the amount of change is small.

The data obtained by the mathematical calculation of the total color change were analyzed by statistically.

Results and discussion

Some statistical values of the total color changes that occur depending on the type of protective material used on the upper surfaces of the test samples at the end of 72 hours are given in Table 3.

Table 3. Some statistical values of the color change in the material obtained from the three-dimensional printer and the wood material

	Printed biomaterial with 30% fill rate			Printed biomaterial with 60% fill rate			Beech		
	water-based varnish	teak oil	control group	water-based varnish	teak oil	control group	water-based varnish	teak oil	control group
Minimum	4.39	3.59	0.80	5.15	3.82	4.87	10.31	3.43	4.33
Maximum	6.71	4.55	14.66	6.27	4.91	9.91	11.87	6.96	7.45
Mean	5.45	4.16	6.40	5.75	4.47	6.44	11.36	5.75	5.56
Standard deviation	0.80	0.41	4.58	0.40	0.37	1.86	0.54	1.32	1.04
Coefficient of variation	14.66	9.83	71.45	6.90	8.22	28.94	4.78	22.92	18.65

Analysis of variance (ANOVA) was performed to determine whether there was a significant difference between the obtained data and the results are given in Table 4.

Table 4. Variance analysis results of total color change

K Value	Source	Degrees of freedom	Sum of squares	Mean square	F Value	Prob $*p \leq 0,05$
2	material (A)	2	78.52	39.26	142.14	0.00
4	time (B)	2	138.70	69.35	251.11	0.00
6	AB	4	8.81	2.20	7.98	0.00
8	varnish type (C)	2	110.92	55.46	200.80	0.00
10	AC	4	127.12	31.78	115.06	0.00
12	BC	4	2.40	0.60	2.17	0.08
14	ABC	8	3.12	0.39	1.41	0.20
–15	error	81	22.37	0.28		
	Total	107	491.96			

According to the ANOVA test results, it was determined that there was a significant difference between material, time, varnish type, material and varnish type, and material and time binary interactions ($p \leq 0.05$). In order to determine the order of the difference between the variables, the DUNCAN test was performed and the results are given in sequential tables.

Table 5. Leveling of total color change depending on material type

Material type	Total color change	
	mean	homogeneity group
Printed bio material with 30% fill rate	3.54	C
Printed bio material with 60% fill rate	4.06	B
Solid beech specimens	5.56	A

LSD = 0,25

As can be seen in Table 5, the maximum color change was observed in the solid beech (5.56) samples. This was followed by printed biomaterials with 60% and 30% fill rates, respectively.

The total color change increases with the increase of the waiting time in the UV device. Accordingly, the maximum color change was obtained at the end of 72 hours (5.95). Increasing the UV time, in other words, as a result of the prolongation of the exposure of the wood material to external factors, the total color change also increases. It is seen that the same result is obtained in different studies on wood material (Bekhta et al., 2022; Gürleyen, 2021).

Table 6. Leveling of total color change over time

Time	Total color change	
	mean	homogeneity group
24 hours	3.31	C
48 hours	3.90	B
72 hours	5.95	A

LSD = 0.25

In the study, when looking at whether the varnish type has an effect on the total color change resulting from the increase in UV time, no significant result was found in the UV time varnish type binary interaction.

As a result of the statistical analysis, when the effect of the varnish type on the total color change is examined, the most change is seen in the test samples varnished with water-based varnish (5.81), followed by unvarnished samples (3.86) and teak oil varnished samples (3.50) is doing.

As a result of the application of shellac paste, paraffin and teak oil to different tree species, it was determined that the highest total color change was in the samples varnished with teak oil (Söğütlü and Sönmez, 2006). The data obtained do not overlap

Table 7. Leveling of the total color change depending on the varnish type

Varnish type	Total color change	
	mean	homogeneity group
Water based varnish	5.81	A
Teak oil	3.50	C
Solid beech specimens	3.86	B

LSD = 0.25

with the results of the previous study. The reason for this may be that the chemical structure of the varnish used in the current study has a greater effect on color change than shellac paste and paraffin.

In the interaction of material and time (Table 8), the maximum total color change was obtained from the beech samples (7.68) that were kept in the UV device for 72 hours. The lowest total color change was observed in the biomaterials printed with 30% (2.70) and 60% (3.10) fill rate, which were kept in UV for 24 hours, and the printed biomaterials with 30% fill rate (3.11), which were kept in UV for 48 hours, although the differences between them were insignificant.

Table 8. Leveling of total color change due to material type and time binary interaction

Material type	Time	Total color change	
		mean	homogeneity group
Printed bio material with 30% fill rate	24 hours	2.70	E
	48 hours	3.11	E
	72 hours	4.81	C
Printed bio material with 60% fill rate	24 hours	3.10	E
	48 hours	3.73	D
	72 hours	5.37	B
Solid beech specimens	24 hours	4.13	D
	48 hours	4.85	C
	72 hours	7.68	A

LSD = 0,43

Considering the binary interaction of material type and varnish (Table 9), the highest total color change was seen in the beech samples varnished with water-based varnish (8.98), whereas the lowest total color change was observed in the samples without beech varnish (3.32) and varnished with teak oil, with 30% (2.97) and 60% (3.16) fill ratios, obtained from wood-added filaments.

Table 9. Leveling of the total color change due to the binary interaction of material type and varnish type

Material type	Varnish type	Total color change	
		mean	homogeneity group
Printed bio material with 30% fill rate	water based varnish	3.85	C
	teak oil	2.97	D
	solid beech specimens	3.82	C
Printed bio material with 60% fill rate	water based varnish	4.60	B
	teak oil	3.16	D
	solid beech specimens	4.43	B
Solid beech specimens	water based varnish	8.98	A
	teak oil	4.37	B
	solid beech specimens	3.32	D

LSD = 0.43

Conclusions

Compared to the color change in solid beech samples, the color change in wood-added biopolymer materials is lower. The regular and homogeneous void texture in the extractives and wood-added biopolymer materials in wood may have an effect on this result.

Increasing the UV rays interaction time increases the color change in solid beech wood and wood-added biopolymer material, with an increase in time-dependent surface structural degradation.

The least color change was observed in teak oil-applied samples, followed by unvarnished samples and water-based varnish-applied samples.

In solid beech, the least color change was seen in the unvarnished samples, while the color change in the water-based varnish-applied samples was higher compared to the teak oil-applied samples.

According to the fill rates, the color change is less in the teak oil applied samples at both 60% and 30% fill rates, and the difference between the color changes in the unvarnished samples and the water-based varnish applied samples is insignificant.

As a result, teak oil provides greater resistance to the color-changing effects of UV rays in both solid wood and wood-added polymeric materials compared to water-based varnishes. In order to ensure that teak oil is used on the surfaces of wooden products used in outdoor environments open to the atmosphere, natural resins used to increase resistance to sunlight, water and moisture, components such as linseed oil, tung oil and naphtha oil, and deeper penetration may be effective on this result. For this reason, it is recommended to use teak oil instead of water-based varnish on the surfaces of products made of both solid wood and wood-added polymeric materials, which are used in outdoor conditions where the interaction with sunlight is highest.

References

Aksu, S., Kelleci, O., Aydemir, D., İstek, A. (2022). Application of acrylic-based varnishes reinforced with nano fillers for conservation of weathered and worn surfaces of the historical and cultural wooden buildings. Journal of Cultural Heritage, 54, 1–11. https://doi.org/10.1016/j.culher.2022.01.003

Aykaç, S., Sofuoğlu, S.D. (2021). Investigation of the effect of varnish types on surface properties used in bamboo wooden material. Journal of Polytechnic, 24(4), 1353–1363. 10.2339/politeknik.683277

Bekhta, P., Krystofiak, T., Lis, B., Bekhta, N. (2022). The impact of sanding and thermal compression of wood, varnish type and artificial aging in indoor conditions on thevarnished surface color. Forests, 13(2), 300–324. https://doi.org/10.3390/f13020300

Budakçı, M., Sönmez, A., Pelit, H. (2012). The color changing effect of the moisture content of wood materials on water borne varnishes. Bioresources, 7(4), 5448–5459. 10.15376/biores.7.4.5448-5459

Ekinci, E. (2011). The determination of the changes on scots pine and chestnut treated with waterborne preservatives exposed to the outdoor conditions, Bartın: Bartın Üniversitesi Fen Bilimleri Enstitüsü.

Gürleyen, L. (2021). Effects of artificial weathering on the color, gloss, adhesion and pendulum hardness of UV system parquet varnish applied to doussie (Afzelia africana) wood. Bioresources, 16(1), 1616–1627. http://dx.doi.org/10.15376/biores.16.1.1616-1627

Pelit, H., Korkmaz, M. (2019). Effect of water-based varnishes added nanographene on the surface properties of beech (*Fagus orientalis* Lipsky) wood. Journal of Polytechnic, 22(1), 203–212. 10.2339/politeknik.385436

Söğütlü, C., Sönmez, A. (2006). The effect of UV lights on color changes on some local wood processed with differential preservatives. Journal of the Faculty of Engineering and Architecture of Gazi University, 21(1), 151–159. https://www.researchgate.net/publication/287590990_The_effect_of_UV_lights_on_color_changes_on_some_local_wood_processed_with_differential_preservatives

Tomak, E.D., Arican, F., Gonultas, O., Sam Parmak, E.D. (2018). Influence of tannin containing coatings on weathering resistance of wood: Water based transparent and opaque coatings. Polymer Degradation and Stability, 151, 154–159. 10.1016/j.polymdegradstab.2018.03.011

TS EN ISO 4892-2. (2013). Plastics – Methods of exposure to laboratory light sources – Part 2: Xenon-arc lamps, 4. Ankara: Turkish Standards Institution. https://www.iso.org/standard/55481.html

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Mycelium material in interior design. Acceptance level amongst future users of new eco-aesthetics

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customer perspective

Abstract

Mycelium-based composites (MBCs) show great potential as a sustainable alternative to conventional biopolymers in the production of environmentally-friendly furniture and interior decor. While these innovative biocomposites have numerous ecological benefits, they pose a new challenge in aesthetics and consumer acceptance. Furniture made from mycelium and lignocellulosic substrates has a porous texture, uneven surface, and unpredictable coloring due to the natural growth patterns of mycelium. Although production methods can be improved and imperfections reduced, the inherent randomness of mycelium growth cannot be eliminated. These factors and the natural provenance of such materials can be a challenge in interior design. For these reasons, it is justified to measure the level of acceptance of such materials as objectively as possible. The article presents and justifies three complementary consumer tests suitable for MBC materials and product acceptance level measuring. The proposed set of consumer tests includes (1) an organoleptic evaluation of the material, using three senses simultaneously, (2) a product acceptance and desirability evaluation, and (3) comparative tests of products with the same function, dimensions, and shape, made of two different materials. The results of these tests are complementary and demonstrate to which extent products made of MBC are potentially acceptable to the public. All of these methods support current and future applications of MBC for manufacturing items where enhanced aesthetics are required.

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Introduction

Interior design and interior decoration mirror *fast fashion*, *a* trend known in the clothing industry. Retail companies specializing in interior design and decoration vigorously promote the vision of often changing collections once or several times during one season (Niinimäki et al., 2020). As in fast fashion in clothing, the environmental costs of fast fashion in interior design are very high (Bick et al., 2018). Consumers are used to permanent purchases, and even the awareness of the problem and negative publicity of fast fashion practices does not always prevail (Roozen and Raedts, 2020). In this situation, the pro-environmental strategy of using environmentally friendly materials could be implemented along with the policy of reducing energy consumption, which is highly reasonable. Following this idea, the authors have begun researching mycelium-based composites (MBCs) in general use. The analysis indicates that MBC could become an alternative to typical materials in sustainable furniture and interior design, despite some known engineering flaws, such as the low ability to transfer tensile forces and high hygroscopicity, resulting in low outdoor durability (Sydor et al., 2022a; 2022b). The use of fungi in the production of MBC usually raises concerns about the health impact, but when compared to MDF, in which formaldehyde or other chemicals are used, MBC seems to be a healthier option.

Using mycelium-based composites (MBCs) to design sustainable furniture and other interior elements raises concerns about aesthetics and acceptance. The question of whether designers and future customers will accept this material is valid and depends on the level of "likeability" of the material (Rifqiya and Nasution, 2016). Even if a material has good physical and economic properties, its lack of acceptance by users can limit its industrial applications (Kwak et al., 2015). This risk is exceptionally high for MBCs, which are difficult to manufacture due to their irregular coloring and surface texture resulting from their natural growth process. Furthermore, the biological origin of MBCs, with both the substrate and the mycelium being biological, can raise concerns among consumers. To successfully introduce new material, it is crucial to ascertain whether potential users are willing to accept MBC for their direct, everyday use, as well as for use in furnishings and other interior design elements. Therefore, research on MBCs should aim to answer these essential questions.

This article aimed to describe potential measurement methods of the level of human acceptance of the new material.

Proposed methods of likeability studies

The research program

Several factors should be considered to assess the organoleptic comfort of new furniture materials. Organoleptic comfort encompasses the sensory experience of a material, including its tactile qualities, aroma, visual appeal, and overall aesthetic appeal. Here are some steps to assess the organoleptic comfort of new furniture materials: sensory testing, evaluating the material's odor, and considering the material's appearance.

Sensory testing evaluates tactile properties, such as texture, softness, and smoothness. This can be done by having individuals touch and feel the material and provide feedback on its comfort. The odor of the material can also impact its overall comfort. To evaluate this factor, individuals can smell the material and provide feedback on its odor and whether it is pleasant. The visual appearance of the material also affects its organoleptic comfort. This includes factors such as color, pattern, and overall aesthetics. Individuals can provide feedback on whether they find the material visually appealing and comfortable. Due to its supraliminal nature, visual perception precedes other sensory experiences when evaluating new objects (Goldstein and Brockmole, 2017). This implies that the visual appearance of a material often exerts a more profound influence on our overall perception of it than other senses, such as touch or smell (Schifferstein and Wastiels, 2014). However, it is crucial to recognize that all senses play a crucial role in our perception of materials and cannot be overlooked in research. Sight provides first impressions; the other senses detail the overall experience and are used in long-term contact with the material. The combined action of several senses gives information complete enough to evaluate the material reliably.

By considering these factors and gathering feedback from individuals, it is possible to assess the overall organoleptic comfort of new furniture materials. This information can then be used to determine whether the material is suitable for furniture design and is likely to be accepted by consumers.

Considering the argument presented, we propose three consumer surveys.

- Test A: Assessing organoleptic comfort (sight, touch, and smell) with a 3-degree scale (methodology partially inspired by (Podrekar Loredan et al., 2022)).
- Test B: Assessing a material acceptance level with a 9-degree scale (methodology inspired by (Lim, 2011)).

- Test C: Comparing two products with the same function and form: made of MBC and made of reference materials and identifying consumer preferences (methodology inspired by (Manuel et al., 2015)).

Respondents

When selecting respondents for furniture material research, it is essential to consider the target market and the study's specific objectives. It can be detailed as:

1. The target market must be defined by identifying the demographic characteristics of the population to be studied. This may include age, gender, income level, education level, occupation, and other relevant factors.
2. The research objectives and the information to be gathered should be considered, such as evaluating the acceptance of new material, understanding consumer preferences for specific material characteristics, or identifying potential areas for improvement in current materials.
3. A sampling method should be selected that is appropriate for the research objectives and target market. This can include probability sampling, where each respondent has an equal chance of being selected, or non-probability sampling, where respondents are selected based on specific criteria or convenience.
4. The appropriate sample size should be decided based on the research objectives, budget, and time constraints.
5. Respondents who meet the target market criteria and are willing to participate in the study should be selected.
6. When selecting respondents, diversity should be considered, including a diverse group of participants to ensure that the results represent the larger population.

Considering the purpose of the tested materials, it is justified to research a group of students who will soon be entering the job market as architects and interior designers, making them a crucial group for understanding the emerging design trends that will shape the future of the product market. Second, the age range of the respondents, 19–24 years, is suitable because they belong to Generation Z, the postmillennial cohort. This generation is known for its increased sensitivity to sustainability and environmental issues, making them the best for evaluating sustainable materials for interior furnishing products. Finally, selecting female and male respondents is likely to ensure that gender-based differences in perception are accounted for, which can be essential in understanding how different gender groups perceive sustainable materials for interior furnishing products. The selected group of respondents should represent a population, ensuring the accuracy and generalizability of the study results.

Tests environment

When material acceptability testing for interior furnishing products is conducted, it is essential to provide three individual sample presentation stands to allow independent evaluation, free from the influence or suggestion of others. Each respondent should only be able to access one stand at a time. The room should be thoroughly ventilated and maintained at a temperature of 22 ±2°C and an air relative humidity of 60 ±5%. The samples should be assessed at a color temperature of 5000K to 10 000K against a neutral, uniform background identical for all the elements presented.

Production of samples

The first stage in producing all MBC samples was to prepare gypsum molds (Fig. 1). The substrate should then be placed in molds with fungus inoculum after five days of growth of the mycelium. After the mycelium has fully colonized the substrate, the molded product is removed and dried. The drying process inactivates the fungus and ensures that the product is stable and durable. The shape and size of the final product are determined by the molds used.

Fig. 1. Wall cladding element before ripening – the form is filled with MBC material (photo by A. Bonenberg)

Fig. 2. Wall cladding element in realization – the panels of chamotte clay (photo by A. Bonenberg)

For example, unglazed and unpainted chamotte clay cladding panels can be used as reference samples. The technology includes: (1) molding into the desired shape and size by extrusion, where the clay is pushed through a die to create a consistent shape, or the clay can be pressed into molds or hand-shaped; (2) drying to remove any excess moisture; (3) firing in a kiln at high temperatures; (4) optionally finishing by glazing or painting, which adds color and protection to the surface. The panels can also be left unglazed for a more natural look. Fig. 2 shows the reference samples prior to firing.

Testing procedure

The first of three consumer tests (test A) was conducted as an organoleptic assessment, requiring using three senses simultaneously. The assessment involved the properties of the test material perceived in the following manner: visual – in terms of color (pleasant, neutral, ugly), olfactory (pleasant, neutral, unpleasant), haptic (pleasant, neutral, unpleasant/hard, difficult to define / warm, neutral, cold).

Test B assesses acceptance and desirability using a 9-point hedonic scale. In this test, respondents should be presented with samples of authentic products with various shapes, flat, convex, and concave, made of mycelium-based composite (MBC) that they could touch, see, and smell. Respondents could be asked: *Would you accept the*

Fig. 3. Test stands for the A, B, and C tests (photo by A. Bonenberg)

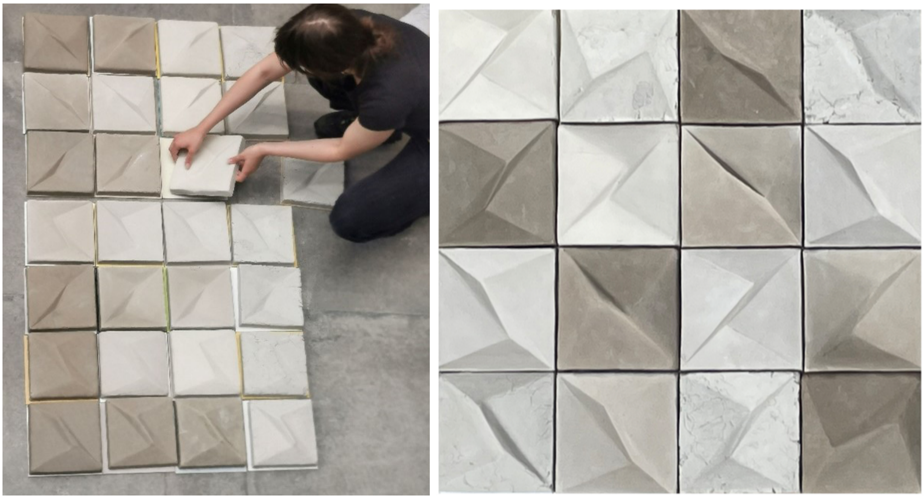

Fig. 4. Evaluation of material acceptance and comparison of wall cladding panels made of MBC and made of chamotte clay (photo by A. Bonenberg)

material in interior design elements in your home? *Would you accept the material in interior design elements in a home that you design with an ecological aesthetic*? The first question concerns a personal opinion on the material, with positive answers indicating a significant positive reception. The second question concerned the respondent's general opinion regarding using the material in interiors.

Test C compares the two products with the same function, shape, and size. It can be a wall cladding made of MBC and alternatively made of chamotte clay, fired and unglazed. This differential, pairwise comparison method tests the solution's potential competitiveness on the market and determines whether the new material would gain consumer acceptance and whether it is 'likable' compared to other solutions.

This testing procedure aims to determine the hedonic quality resulting from evaluations of sensory experience in terms of subjective emotions, both raw materials and end products. Fig. 3 shows the exemplary test stands for the A, B, and C tests.

Fig. 4 shows the pairwise comparison of the exemplary products during the C test.

Fig. 5 shows sample products made of MBC that can be used in consumer tests.

During all the test, the respondents could not influence each other's responses.

Fig. 5. Sample products made of MBC (photo by A. Bonenberg)

Conclusions

Studying the material properties of manufactured products in the context of introducing new materials and applying this knowledge to industrial design is a challenge in product design (Petiot and Yannou, 2004). Due to the subjectivity and different nature of user needs, it is difficult to assess and quantify these characteristics accurately. In this article, the authors relied on usability testing and used traditional marketing and decision-making theory methods, i.e., two one-step consumer tests and pairwise comparison. This approach has provided data that helps to understand and identify the requirements of future users.

Using the proposed methodology enables:

1. A better understanding of consumer needs and preferences by gaining a more detailed understanding of how consumers perceive and interpret product semantics, which can inform decisions related to product design and development.
2. Improving product specifications by providing a framework for specifying product attributes and characteristics based on consumer perceptions can improve product specifications' accuracy and relevance.

3. Enhancing product evaluation by a more precise and comprehensive evaluation of product performance and user experience can improve product quality and consumer satisfaction.
4. Increasing competitiveness by incorporating consumer perceptions into the design process, companies can develop products that better meet consumer needs and preferences, potentially resulting in a competitive advantage in the market.

The potentially positive evaluation of the mycelium-based composite (MBC) among respondents will demonstrate that the continued development of the material in question could yield good commercialization results in the coming years (Sydor et al., 2022a; 2022b). Working with this and other biomaterials can lead to a paradigm shift in aesthetics in which the design mainstream has hitherto been defined by high technology and highly sophisticated design and production methods, which will perhaps soon take on a more casual, nature-like form.

References

Bick, R., Halsey, E., Ekenga, C.C. (2018). The global environmental injustice of fast fashion. Environ Health, 17, 92. https://doi.org/10.1186/s12940-018-0433-7

Goldstein, E.B., Brockmole, J.R. (2017). Sensation and perception (10th ed.). Cengage Learning, Australia, Boston, MA.

Kwak, H.S., Ahn, B.-H., Kim, H.-R., Lee, S.-Y. (2015). Identification of senory attributes that drive the likeability of korean rice wines by american panelists: Drivers of liking for Korean rice wines. Journal of Food Science, 80, S161–S170. https://doi.org/10.1111/1750-3841.12739

Lim, J. (2011). Hedonic scaling: A review of methods and theory. Food Quality and Preference S0950329311000954. https://doi.org/10.1016/j.foodqual.2011.05.008

Manuel, A., Leonhart, R., Broman, O., Becker, G. (2015). Consumers' perceptions and preference profiles for wood surfaces tested with pairwise comparison in Germany. Annals of Forest Science 72, 741–751. https://doi.org/10.1007/s13595-014-0452-7

Niinimäki, K., Peters, G., Dahlbo, H., Perry, P., Rissanen, T., Gwilt, A. (2020). The environmental price of fast fashion. Nature Reviews Earth & Environment, 1, 189–200. https://doi.org/10.1038/s43017-020-0039-9

Petiot, J.-F., Yannou, B. (2004). Measuring consumer perceptions for a better comprehension, specification and assessment of product semantics. International Journal of Industrial Ergonomics, 33, 507–525. https://doi.org/10.1016/j.ergon.2003.12.004

Podrekar Loredan, N., Lipovac, D., Jordan, S., Burnard, M.D., Šarabon, N. (2022). Thermal effusivity of different tabletop materials in relation to users' perception. Applied Ergonomics, 100, 103664. https://doi.org/10.1016/j.apergo.2021.103664

Rifqiya, A., Nasution, R.A. (2016). Sensory marketing: The effect of tactile cue on product packaging towards perceived novelty and perceived likeability. Journal of Business and Management, 5, 352–361. https://core.ac.uk/download/pdf/304293847.pdf

Roozen, I., Raedts, M. (2020). The power of negative publicity on the fast fashion industry. Journal of Global Fashion Marketing, 11, 380–396. https://doi.org/10.1080/20932685.2020.1798802

Schifferstein, H.N.J., Wastiels, L. (2014). Sensing materials. Exploring the Building Blocks for Experiential Design. In: Materials Experience: Fundamentals of Materials and Design (pp. 15–26). Elsevier, Oxford, England. https://doi.org/10.1016/B978-0-08-099359-1.00002-3

Sydor, M., Bonenberg, A., Doczekalska, B., Cofta, G. (2022a). Mycelium-based composites in art, architecture, and interior design: a review. Polymers, 14, 145. https://doi.org/10.3390/polym14010145

Sydor, M., Cofta, G., Doczekalska, B., Bonenberg, A. (2022b). Fungi in mycelium-based composites: Usage and recommendations. Materials, Biomaterials, 15, 6283. https://doi.org/10.3390/ma15186283

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Influence of SW-CNT on lignin-based nanofibrillated cellulose biofilms: chemical, thermal, thermo-mechanical, and morphological properties

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Keywords

SW-CNT
CNF
lignin
biofilm
thermo-mechanical property

Abstract

This study examined the single wall-carbon nano tube (SW-CNT) effect on the lignin-based nanofibrillated cellulose (CNF) biofilms. For that purpose, CNF and lignin-based CNF interacted with hydrophilic SW-CNT through the casting process to form films. After the formation of the films, chemical, thermal, thermo-mechanical and morphological characterization was conducted by using FT-IR, TGA, DMA, and SEM, respectively. At the end of the study, some minor shifts, and new vibrations were observed after lignin. Higher thermal stability was seen after the SW-CNT, whereas the value lowered with the lignin. DMA reveals that the SW-CNT make it increases both Tg and storage modulus. Also, SEM reveals that all films formed an entangled network in the matrix. As a result, it was seen that those biofilms could be easily prepared and applied in many industrial areas according to necessary.

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Introduction

Lately, many materials have been used in a wide range of applications with ever-increasing industry demand. Materials which mostly preferred by industry are biopolymers owing to their biodegradability properties. The most popular biopolymer is cellulose which consists of anhydroglucose units and has been used in applications thanks to its prospective mechanical properties. The cellulose with different types, which are nano fibrillated cellulose (CNF) and nano crystalline cellulose (CNC) is isolated or synthesized from plants or bacteria via a "top-down" and "bottom-up" process (Klemm et al, 2011). Of those types, the CNF has attracted much interest as it reveals a higher aspect ratio, more flexibility and stronger interfacial adhesion over CNC. Therefore, it has been applied in numerous fields ranging from bioactive paper to electronic films (Lin and Dufresne, 2014). In addition to CNF, lignin has atracted many interests as it exhibits a high elastic modulus compared to cellulose and hemicellulose. Lignin which consists of aromatic-based structures like phenylpropanoid units (*p*-hydroxyphenyl (H), guaiacyl alcohol (G), and syringyl alcohol (S) are found in a three-dimensional network and has important biological functions such as water transport, mechanical support, and resistance to various stresses. Besides, lignin is also one of the most frequently researched materials after cellulose, owing to its renewability, abundance, sustainability as well as other features such as its stabilizing effect, reinforcing effect, and UV absorption (Kun and Pukanszky, 2017).

Though many materials have been used with nano cellulose and lignin, there is a limited study related to single wall carbon nanotube (SW-CNT). SW- CNT are viewed as rolled-up structures of single sheets of graphene and individual carbon structures have sp^2 hybridization of carbon atoms along with diameters between 0.7 and 10 nm as well as high length/diameter ratio. Besides, SW-CNT reveals a high young modulus and thermal/electrical conductivity. For that purpose, there has been many studies related to the SW-CNT (Osmani et al, 2014).

In a study, Wang et al. (2014) conducted the axial strength of MW-SW-CNTs and reported its elastic modulus values ranging from 200 to 400 GPa; the bending modulus is to 14 GPa, as well as compression strength is about 100 GPa. In another study, Wong et al. revealed that the high deformation of SW-CNTs allows it to break when tensile strength reaches 18% (Wong et al., 1977). Treacy et al. measured the elastic modulus of MW-SW-CNTs to be 1TPa, on the same level as a diamond. They stated that the mechanical strength of the SW-CNT is 100 times higher of steel when compared with steel, but the density is only one sixth of the steel (Treacy et al, 1996). Therefore, it is believed that the incorporation of SW-CNT into matrix may be able to enable to higher mechanical properties (Wang et al., 2014). However, though many studies related to SW/MW-CNT, there is no SW-CNT based biofilms containing the CNF and lignin. Therefore, in this study, the SW-CNT was used to investigate the chemical, thermal, thermo-mechanical and morphological properties of the lignin based CNF film and CNF film. It is thought that this study will make extra contribution researchers studying on biofilms.

Methods and materials

Pulp preparation

500 g of *Eucalyptus camaldulensis* chips were cooked in a digester (sulphidity charges, 28%; active alkali, 18%; and wood/liquor, 5:1) (Uniterm Rotary Digester, Uniterm Lab.) to obtain kraft pulp. Afterward, the obtained kraft pulp was screened to 0.15 mm and bleached using the oxygen-chlorine dioxide-alkaline-peroxide (ODEP) process. The pulps' viscosity (SCAN-CM 15–62 standard) and kappa number (Tappi T236) were determined for each bleaching stage. Then, the kraft pulp was delaminated for mechanical fibrillation by using a blender (2% w/w, 5 min interval, 30°SR) (NuBlend, Waring Commercial) and high-pressure homogenizator (first, one-pass, diameter of 200 µm, 96.5 MPa; second, five-pass, diameter of 100 µm, 165.5 MPa, Z-shaped chamber size, 2% w/w) using a microfluidizer (M-110Y, Microfluidics Corp.).

Sulpho lignin preparation

The obtained alkali lignin (alkali, Powder, 370959, Sigma) was converted to sulphoxide lignin via a chemical sulphide reaction in order to gain hydrophilic properties. For that purpose, the alkali lignin was reacted 2 g of sodium sulfide (407410-50G, Sigma) at 70 °C, 90 min. Following reacted with 30 ml NaOH (0.8 M) (> 99.9, Merck) and 1.5 ml formaldehyde (15512-2.5L-R, ≥34.5 wt. %, Sigma) in 400 rpm 30 min at the RT.

Film preparation

For the films, 20 ml at 10 wt.% of the CNF suspension, 20 ml Disodium 2,2'-(1,1'-biphenyl]-4,4' diyldivinylene) bis(sulphonate) modified SW-SW-CNT (302, Tuball) and 20 ml sulpho lignin was added and mixed at 80°C prior to sonication for 2 min. Finally, the solution was cast onto a glass plate with controlled leveling, and then dried for seven days at room temperature. Then, Films were designated as C (CNF), CS (CNF+SW-SW-CNT), and CSL (CNFSW-CNT+ Lignin).

Characterization

Chemical alterations were investigated with ATR-FTIR (IR Prestige-21, Shimadzu) by putting on the attachment to investigate and elucidate chemical alterations as vibrations in the range of 4000 to 600 cm^{-1} with a resolution of 4 cm^{-1}, and 20 scans. Thermal stability was determined with a thermogravimetric analysis (TGA) device equipped with a thermal analysis data station (Shimadzu, DTG 60). For that purpose, approximately 10 mg of films were gently placed in the Pt pan. Then, films was exposed to heat from 25 to 800°C at a 10°C/min heating rate and under a 75 ml/min N_2 (nitrogen) atmosphere. DTMA tests were carried out to determine the thermo-mechanical characteristics of the produced films. The tests were performed in tension mode at a controlled heating rate of 10°C/min. The temperature was increased from 30°C to 250°C at an oscillatory frequency of 1 Hz. Morphological analysis of films was carried out with an SEM (Quanta 250, FEI) to investigate the surfaces and cross-sectional distribution of films.

Results and discussion

Chemical characterization

FTIR spectra of the C, CS and CSL films were given in the Fig. 1.

CH asymmetric and symmetric vibrations sourced from methylene groups in the structures were seen at 2926 and 2854 cm^{-1} for CSL while those vibrations were seen as overlap for C film at 2901 cm^{-1}. Aromatic CH vibration was observed at 1594 cm^{-1} for CSL that is related to aromatic ring found in lignin. C_1-O-C_5 inter molecular vibration were seen at 1162 cm^{-1} for C and CS. However, those vibrations were not observed in the CSL. Intra molecular C_1-O-C_4 vibration were seen at 1030 cm^{-1} both CS and C.

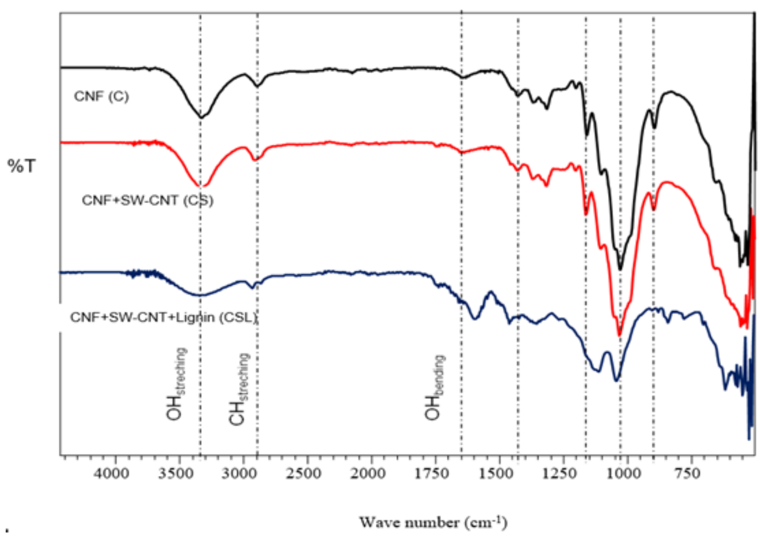

Fig. 1. FTIR spectra of the C, CS and CSL films

However, that vibration were shifted to higher wavelengths and observed at 1040 cm^{-1} for CSL. This circumstance reveals that cellulose structure exposured chemical alteration after adding the lignin to the polymer matrix. In addition to C_1-O-C_4 vibration, glycosidic deformation that sourced from ring stretching OH were observed for the CS and C while that no vibration was observed in that region for the CSL.

Thermal analysis

Thermogram of the films is given in Fig. 2.

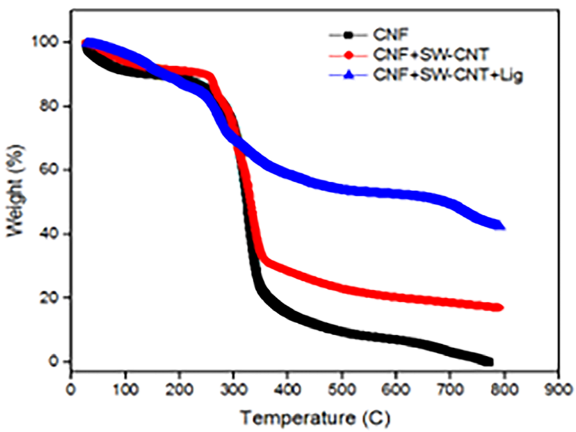

Fig. 2. Thermogram of the C, CS and CSL films

Thermal degradation curves revealed mostly similar behavior for the C and CS films. Those thermograms were seen as a single stage whereas for the CSL film was observed as no one stage. T_{50} % degradation values were investigated in detail for determining thermal stability. It was observed that the lowest thermal stability was seen at CSL whereas the highest stability was seen at CS. Therefore it can be said that carbon nano tube (SW-CNT) enabled higher thermal stability. This circumstance reveals that higher energy was needed to destroy the interaction of molecular chains. This may be attributed to the fact that SW-CNT comprises a large amount of folded-up molecules and required higher energy to move (Sun and Liu, 2021). Besides, this circumstance can be explained with lignin. After adding the lignin, chain mobility was restricted in the matrix on the long range (Shimazaki et al., 2007).

Besides, it can be said that the CNF degraded completely, while biopolymers having SW-CNT left some residue.

Mechanical analysis

The thermo-mechanical behavior of films was studied by DMA. The obtained results were given as storage moduli and tan delta in Fig. 3-a and 3-b, respectively.

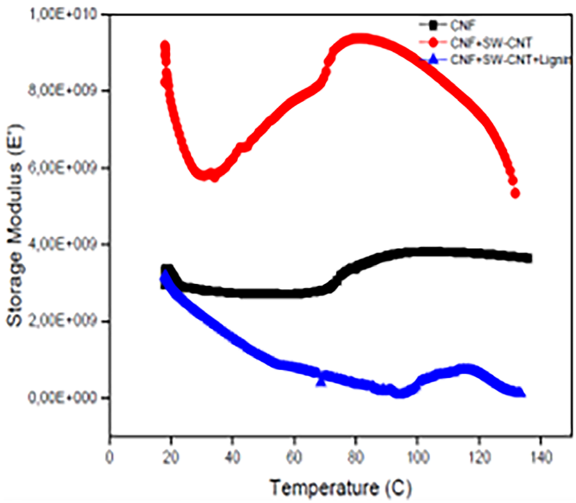

Fig. 3-a. Storage Modulus of the C, CS and CSL films

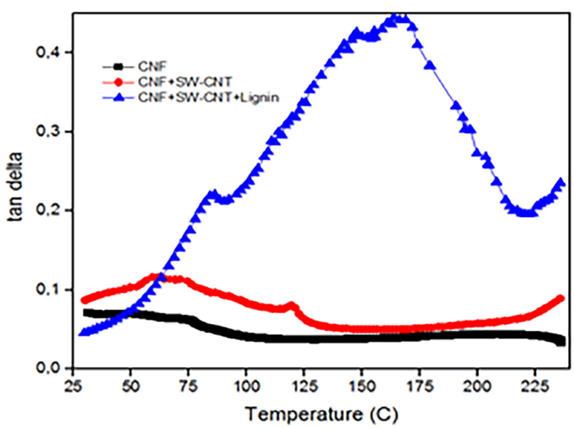

Fig. 3-b. Tan δ of the C, CS and CSL films

When the storage modulus, which give insight into elastic capability and behavior of films for storing energy, investigated in the Figure 3-a, fluctuating behavior were observed for CSL film. This is may be due to single wall graphene lattice which folded-up properties of the carbon nanotube. After lignin, this level lowered that the lowest value was seen in the CSL. Generally, storage modulus increased with SW-CNT due to SW-CNT having stiffness property since SW-CNT enable high modulus in higher temperatures (Jin et al., 2001; Szcześniak et al., 2008).

E′ (storage modulus) which is representative of the elastic behaviour and E″ (loss modulus) is the loss modulus indicative of the lost energy due to the resistance to flow of the polymer chains, the ratio between E″/E′ is known as tan δ (delta), the maximum of this ratio is defined as the Tg (Velasco-Santos et al., 2003).

The storage modulus changes with temperature as the molecular or chain mobility, interfacial interactions altered within the polymer matrix. There is no considerable alteration in the C film that revealed mostly singular behavior. However, after adding the SW-CNT, polymer matrix showed a different behavior that the presence of carbon nanotubes enables CSL films to sustain higher Tg value due to the fact that broad of the tan delta peak since carbon nano tube has high elastic modulus and stiffness. The different natures of the SW-CNT and lignin played a major role in determining the extent of tan δ broadening whereas in the presence CNF, CSL revealed more broadening peak when compared to C films (Panwar and Pal, 2017).

Morphological properties

Surface pictures of the C, CS and CSL films were taken with SEM as 100 μm and 1 μm dimensions and the obtained pictures were given in Fig. 4.

Fig. 4 depicted the surface morpology of the films. Amorph fibrils particles were observed both C and CS. Also, amorp fibrils in the C film have nano scale and their dimensions were ranged from 20 nm to 50 nm as well as those revealed entanglement network. Also, SW-CNT and lignin was well embedded within the polymer matrix and there is no gross phase for CSL film. In addition, it was seen that there is no considerable aggregation as well as no considerable cracks and voids were observed on the films. Overall, it can be said that SW-CNT and lignin particles were dispersed homogenously in the films.

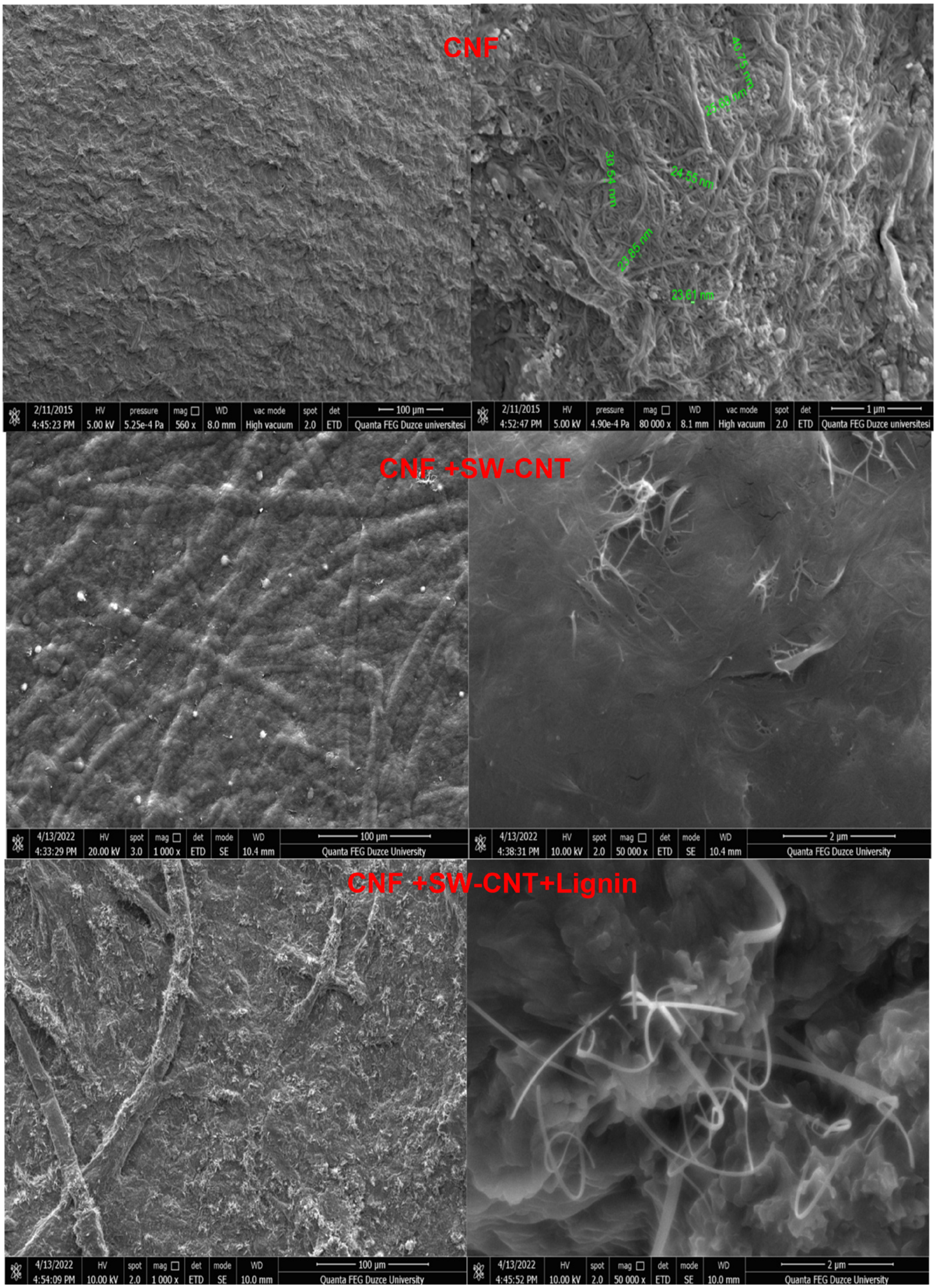

Fig. 4. Surface pictures of C, CS, CSL films

Conclusions

Overall, CNF, CNF+SW-CNT, and CNF+SW-CNT+lignin biofilms have been produced successfully via the casting process. Films had a homogenous surface structures which has fibrils having nano dimensions. In the chemical structure, new vibrations were observed due to the fact that having the aromatic structure of lignin whereas caused the lower thermal stability on the film. Contrary to lignin, SW-CNT enabled higher thermal stability. As for thermo-mechanical properties, SW-CNT enabled higher storage modulus and Tg value. This study reveals that SW-CNT and lignin influenced the film's chemical, thermal, and thermo-mechanical properties differently.

References

Jin, Z., Pramoda, K. P., Xu, G., Goh, S.H., 2001. Dynamic mechanical behavior of melt-processed multi-walled carbon nanotube/poly (methyl methacrylate) composites. Chemical Physics Letters. 337(1–3), 43–47. https://doi.org/10.1016/S0009-2614(01)00186-5

Klemm, D., Kramer, F., Moritz, S., Lindström, T., Ankerfors, M., Gray, D., Dorris, A. (2011). Nanocelluloses: a new family of nature-based materials. Angewandte Chemie International Edition, 50(24), 5438–5466. https://doi.org/10.1002/anie.201001273

Kun, D., Pukanszky B. (2017). Polymer/lignin blends: Interactions, properties, application. European Polymer Journal, 93, 618–641. 10.1016/j.eurpolymj.2017.04.035

Lin, N., Dufresne, A. (2014). Nanocellulose in biomedicine: Current status and future prospect. European Polymer Journal, 59, 302–325. https://doi.org/10.1016/j.eurpolymj.2014.07.025

Osmani, R.M., Kulkarni, A.S., Aloorkar, N.H., Bhosale, R.R., Ghodake, P.P., Harkare, B.R. (2014). Carbon nanotubes: an impending carter in therapeutics. International Journal of Pharmaceutical and Clinical Research, 6(1), 84–96. https://www.researchgate.net/publication/261548910_Carbon_Nanotubes_An_Impending_Carter_in_Therapeutics

Panwar, V., Pal, K. (2017). Dynamic mechanical analysis of clay–polymer nanocomposites. In: Clay-polymer nanocomposites (pp. 413–441). Elsevier. https://doi.org/10.1016/B978-0-323-46153-5.00012-4

Shimazaki, Y., Miyazaki, Y., Takezawa, Y., Nogi, M., Abe, K., Ifuku, S., Yano, H. (2007). Excellent thermal conductivity of transparent cellulose nanofiber/epoxy resin nanocomposites. Biomacromolecules, 8, 2976–2978. https://doi.org/10.1021/bm7004998

Sun, N., Di, M., Liu, Y. (2021). Lignin-containing polyurethane elastomers with enhanced mechanical properties via hydrogen bond interactions. International Journal of Biological Macromolecules, 184, 1–8. https://doi.org/10.1016/j.ijbiomac.2021.06.038

Szcześniak, L., Rachocki, A., Tritt-Goc, J. (2008). Glass transition temperature and thermal decomposition of cellulose powder. Cellulose, 15(3), 445–451. https://doi.org/10.1007/s10570-007-9192-2

Treacy, M.M.J., Ebbesen, T.W., Gibson, J.M. (1996). Exceptionally high Young's modulus observed for individual carbon nanotubes. Nature, 381, 6584, 678–680. https://doi.org/10.1038/381678a0

Velasco-Santos, C., Martinez-Hernandez, A.L., Fisher, F., Ruoff, R., Castano, V.M. (2003). Dynamical–mechanical and thermal analysis of carbon nanotube–methyl-ethyl methacrylate nanocomposites. Journal of Physics. Ser. D: Applied Physics, 36(12), 1423. https://doi.org/10.1088/0022-3727/36/12/311

Wang, W., Zhu, Y., Liao, S., Li, J. (2014). Carbon nanotubes reinforced composites for biomedical applications. BioMed Research International. https://doi.org/10.1155/2014/518609

Wong, E.W., Sheehan, P.E., Lieber, C.M. (1997). Nanobeamme mechanics: elasticity, strength, and toughness of nanorods and nanotubes. Science, 277, 5334, 1971–1975. 10.1126/science.277.5334.1971

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Considering lateral loads of multi-stapled and glued alder wood joints connected with two different gusset-plates

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Keywords

staple
gusset-plate
wood joint
glue
alder

Abstract

Lateral shear strengths of the glued and multi-stapled (2, 4, 6, 8) alder joint attached with two different gusset-plates (plywood and beech) were investigated. Results indicated that the glued and multi-stapled joints with plywood gusset-plate indicated increasing trend from 2 staple to 6 staple for each 2 staple increments, however; the ones with beech gusset-plate indicated the highest strength in the joints with glue and 2 staples. The joints with plywood gusset-plate mostly failed gusset-plate bending or shearing between layers. On the other hand, the joints with beech wood gusset-plate failed with the mode of staple legs withdrawn from main members and staple legs bent and materials underneath of staple legs crushed in main and side members. Additionally, this study revealed that using plywood gusset-plate in glued-multistapled did not show the exact strength of the joints and showed different shaped of load-displacement curves compared to the ones with beech gusset-plates. The glued and multistapled joints with beech gusset-plate showed a load-displacement curve in a manner for each 2 staple increment for all furniture joints.

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Introduction

Alder wood has been recently widely used in the Turkish furniture manufacturing industry. The increased use of alder wood as upholstery furniture frame stock is due to several of its inherent advantages such as being very common wood specie in Blacksea region of Türkiye and being of the fast growing wood specie in Türkiye compared to beech wood which is one the most popular wood material in Turkish furniture industry, especially in sofa frame making.

Staple-connected, gusset-plate joints were considered in this study because of their wide use in upholstered furniture frame manufacturing. The gusset-plate joints, connected with power-driven multi-staples and glue, are commonly used at very critical joints in sofa frames. A gusset-plate joint is a point in a frame structure where two members are connected with plates fastened to the member sides with glue and fasteners driven perpendicularly through the plates into the member faces (Demirel, 2012).

The strength design of upholstered furniture frames constructed of wood needs fundamental information on static lateral resistances of joints with various configurations (Zhang and Maupin, 2004) such as different type of component like gusset-plate and also connected with different types of fasteners like staple. Since staples are very practical for attaching furniture parts, they are the most commonly used mechanical fasteners to attach structural members in upholstered furniture frames (Erdil et al., 2003; Demirel et al., 2013; 2016; Demirel and Zhang, 2014; 2018). Limited information exists on the lateral resistance of staple-connected joints in alder wood for furniture frame construction, especially about the data related to the lateral resistance of multi-staple connected joints.

The main objective of this study is to investigate the lateral shear resistances of gusset-plate joints. The specific objectives were to investigate the effect of using different gusset-plate materials on the lateral shear resistances of the multi-staples and glued wood joints and investigate the manner of load-displacement curves of the joint based on staple increment.

Methods and materials

Materials

The general view of the joint samples for this study is shown in Fig. 1. The specimen consisted of two principal structural members, a main member (base member) and

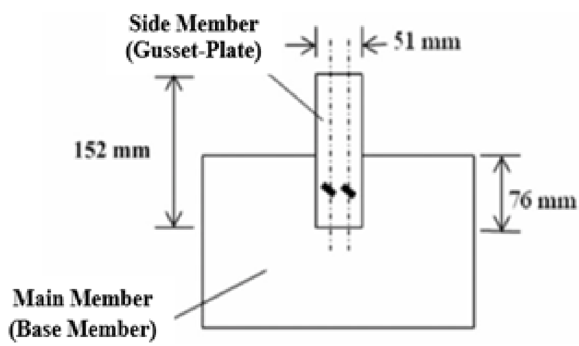

Fig. 1. General view of a glued gusset-plate wood joint connected with multi-stapled and glue

a side member (gusset-plate), assembled together by multi-staple and glue. The main member was alder. The gusset-plate were produced from pine plywood and beech wood. 40 multi-stapled and glued joints prepared with plywood gusset-plate while 40 of them prepared with beech gusset-plate.

Methods

Joint specimen preparation and testing

Before joint preparation, all cut base member and gusset-plates were conditioned in an equilibrium MC chamber controlled at 25 ±5ºC temperature and 45 ±5 percent relative humidity. In the joint attactment, glue was applied member then staples were driven to them. All tests were carried out right after 48 hours for glue curing between the joints members in the laboratory conditions (23 ±2ºC and 50 ±5%).

Fig. 2 illustrates the test setup for measuring the lateral shear resistance of joints. All joints were tested on a Universal MTS Criterion 45 testing machine at a loading rate of 2,5 mm/min in reference with ASTM D 1761 (ASTM 2010). In joint preparation, the joint sample was first clamped in Universal MTS machine and loading head

Fig. 2. Test setup for measuring the lateral shear resistance of joints

was calibrated before loading. After the loading initiated, ultimate lateral shear load, load-displacement curves, and specimen failure modes were recorded.

Results and discussion

Load-displacement curve

Figures 3, 4, 5, and 6 indicate the load-displacement curves of the glued and multi-staple joints connected with plywood gusset-plates. As shown in the figures, only one peak was observed in each graph no matter which staple number was used. Additionally, no clear trend was observed among the load-displacement curves based on the staple number of 2, 4, 6, and 8.

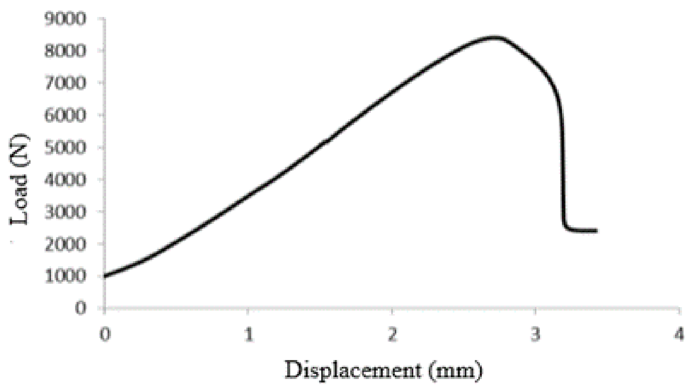

Fig. 3. 2 stapled and glued joint with plywood gusset-plate

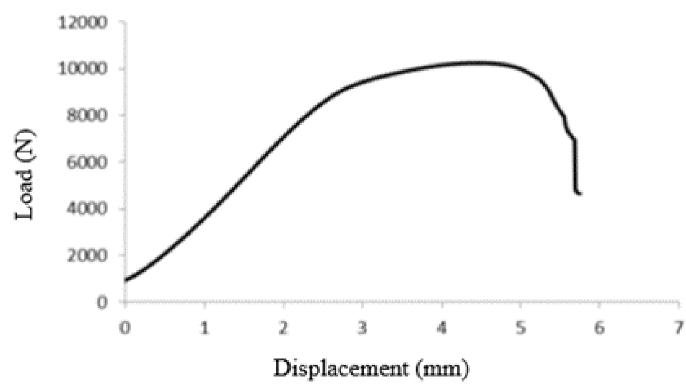

Fig. 4. 4 stapled and glued joint with plywood gusset-plate

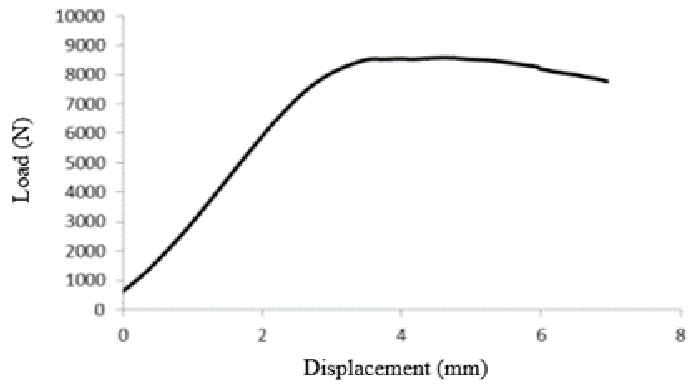

Fig. 5. 6 stapled and glued joint with plywood gusset-plate

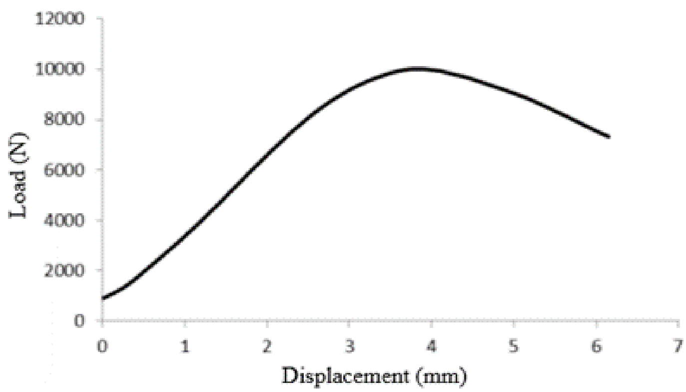

Fig. 6. 8 stapled and glued joint with plywood gusset-plate

Table 1 indicates the average lateral shear resistances of multi-stapled and glued joints connected with plywood gusset-plates. Based on the table, that the glued-multistapled joints with plywood gusset-plate indicated increasing trend from 2 staple to 6 staple for each 2 staple increment. Increasing number of staple increased the strength of the joint (Demirel et al., 2013; Demirel and Zhang, 2014; Demirel et al., 2016; 2018).

Figs 7, 8, 9, and 10 indicate the load-displacement curves of glued and multistapled joints connected with plywood gusset-plates. Figure 7 has only one peak, on the other hand Figures 8, 9 and 10 have two peaks which belong glue and staple connections separately and successively.

Table 1. Lateral shear resistances of multi-stapled and glued joints connected with plywood gusset-plates

Number of sample	Number of staple			
	2	4	6	8
1	9 338	10 191	9 655	9 660
2	8 312	9 387	10 593	9 523
3	8 116	8 305	9 135	9 651
4	7 648	10 244	7 744	10 140
5	10 374	11 176	11 162	9 367
6	6 991	8 334	9 680	9 740
7	8 689	9 075	9 669	8 478
8	7 928	8 300	10 818	7 423
9	9 227	11 607	11 048	10 014
10	6 694	10 122	8 573	8 851
Average	8 332	9 674	9 808	9 285

A sharp curve after maximum point is very common behavior for the joints with glue connection (Demirel and Kalayci, 2019). Demirel 2012 indicated a similar curve for OSB based furniture joint connected with only glue. In current study, Fig. 7, 8, 9 and 10 shows a sharp behavior beloging to glue behaviour.

Based on the figures, load-displacement curves indicates a manner. To explain this manner more clearly, it may be said that the 2 stapled-glued joint with beech gusset-plate indicated only glue connection by showing only one peak while 4, 6, and 8 stapled-glued joint with beech gusset-plate indicated glue and staple connection by showing two succesive peaks. Especially, the second peak of the joint with 8 stapled-glued is higher and stronger compared to the others.

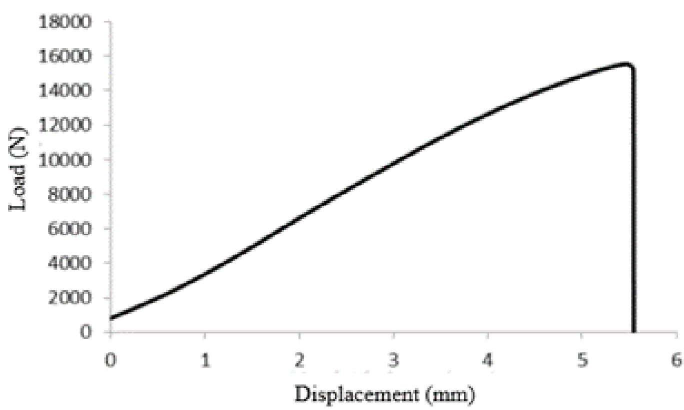

Fig. 7. 2 stapled-glued joint with beech gusset-plate

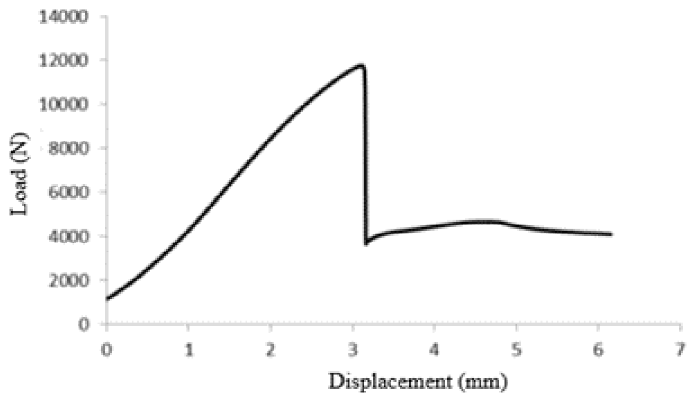

Fig. 8. 4 stapled-glued joint with beech gusset-plate

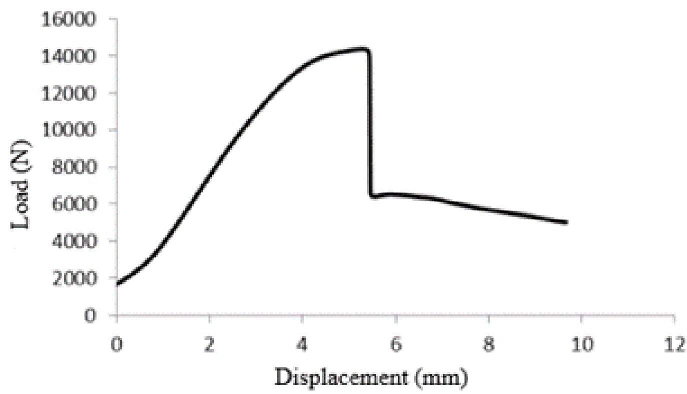

Fig. 9. 6 stapled-glued joint with beech gusset-plate

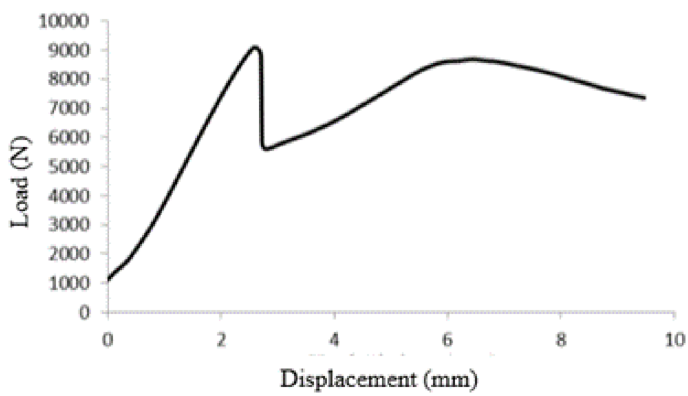

Fig. 10. 8 stapled-glued joint with beech gusset-plate

Table 2 indicates average lateral shear resistances of multi-stapled and glued joints connected with beech gusset-plates. Results indicated that the multi-stapled and glued joints with beech wood gusset-plate indicated highest strength in the joints with 2 staples. This could be explained with using more than 2 staples causes weaker wood and glue structure.

Table 2. Lateral shear resistances of multi-stapled and glued joints connected with beech gusset-plates

Number of sample	Number of staple			
	2	4	6	8
1	11 243	15 143	12 174	14 165
2	15 546	11 208	8 823	10 388
3	14 056	12 468	12 458	14 060
4	13 877	12 828	11 436	13 215
5	20 870	7 298	11 361	9 093
6	16 583	11 766	14 317	11 439
7	12 138	14 956	14 382	15 154
8	9 041	12 087	13 556	14 156
9	14 916	15 084	12 246	12 315
10	15 342	13 414	12 161	13 116
Average	14 361	12 625	12 292	12 710

Failure mode

Figure 11 shows failure modes of glued and multi-stapled joints connected with plywood gusset plates. Based on the results, 24 out of 40 joints with plywood gusset-plate failed with gusset-plate layer shear, 9 out of 40 joints failed with separation between members, and 7 out of 40 joints failed with main member rupture.

Figure 12 shows failure modes of glued and multi-stapled joints connected with beech gusset plates. Based on the results, 39 out of 40 joints connected with beech gusset-plate failed with separation between members while only one joint failed with main member rupture. This result indicated that using beech gusset-plate allows to see real strehgt of the joints because beech gusset-plate did not fail itself compared to plywood gusset-plate, which showed shear among the layers. Demirel and Kalayci, 2019 found that a typical load-displacement curve of the only glue connected joints with pine plywood gusset plate did not show a sharp behavior after ultimate point. They stated that this could be a reason of failure mode because most of the joints with plywood gusset-plate failed with shear among gusset plate layers. This type of failure did not allow to show a sharp behavior after ultimate point.

Fig. 11. Failure modes of the joints: a) shear among the layers of gusset-plate; b) seperation from connection points; c) main member rupture

Fig. 12. Failure modes of the joints: a) seperation from connection points; b) main member rupture

Conclusions

The alder wood joints constructed with multi-staple (2, 4, 6, 8) and gusset-plates (pine plywood and beech wood) were mechanically tested, their lateral shear resistances were investigated and compared.

Results indicated that the glued-multistapled joints with plywood gusset-plate indicated increasing trend in strength from 2 staples to 6 staples for each 2 staple increment, however; the ones with beech gusset-plate indicated highest strength in the joints with glue and 2 staples.

The joints with plywood gusset-plate mostly failed gusset-plate shearing between layers. On the other hand, the joints with beech wood gusset-plate failed with separation between the members.

Additionally, this study revealed that using plywood gusset-plate in glued-multistapled did not show the exact strength of the joints and showed different shaped of load-displacement curves compared to the ones with beech gusset-plates. The glued-multistapled joints with beech gusset-plate showed load-displacement curve in a manner for each 2 staple increment for all furniture joints.

References

ASTM 2010. Standard test method for mechanical fasteners in wood. American Society for Testing and Materials. ASTM D 1761. 2010. ASTM International: West Conshohocken, PA, USA. https://www.astm.org/Standards/D1761.htm

Demirel, S. (2012). Static and fatigue performance of oriented strandboard as upholstered furniture frame stock. PhD dissertation. Mississippi State University, Starkville, MS.

Demirel, S., Kalayci, G. (2019). Comparison of using different gusset-plate member in wood joints. 4th International Scientific Conference, Wood Technology & Product Design, 2019, Ohrid, Republic of North Macedonia, 179–185. https://avesis.ktu.edu.tr/yayin/580f56cf-3239-43e8-ade1-1f104a28b142/comparison-of-using-different-gusset-plate-memberin-wood-joints

Demirel, S., Kalayci, G. (2020). Measuring and Estimating Shear Force of One Stapled and One-Row Multi Stapled Wood Joints. Maderas Ciencia y Tecnologia, 22(3), 395–404. DOI: 10.4067/S0718-221X2020005000313

Demirel, S., Zhang, J., Jones, D., Kitchens, S., Martin, W.V., Yu, H. (2013). Face lateral shear resistance of one-row multistaple joints in oriented strandboard. Forest Products Journal, 63(5–6), 207–212. http://dx.doi.org/10.13073/FPJ-D-12-00073

Demirel, S., Zhang, J. (2014). Face lateral resistance of oriented strandboard joints connected with two rows of 16-gauge coated staples. Wood and fiber science: journal of the Society of Wood Science and Technology, 46(2), 280–290. https://www.researchgate.net/publication/270448705_Face_lateral_resistance_of_oriented_strandboard_joints_connected_with_two_rows_of_16-gauge_coated_staples

Demirel, S., Yu, X., Tor, O., Zhang, J. (2016). In-plane bending moment resistance of T-shaped one-sided two-gusset-plate furniture joints in oriented strandboard. Wood and Fiber Science, 48(3), 1–9.

Demirel, S., Tor, O., Yu, X., Zhang, J. (2018). Lateral loads of stapled glued surface-to-surface joints in oriented strandboard for furniture. Wood Fiber Sci 50(3): 280–290. https://dx.doi.org/10.22382/wfs-2018-028

Erdil, Y.Z., Zhang, J., Eckelman, C.A. (2003). Staple holding strength of furniture frame joints constructed of plywood and oriented strandboard. Forest Products Journal, 53(1), 70–75. https://go.gale.com/ps/i.do?id=GALE%7CA97740268&sid=googleScholar&v=2.1&it=r&linkaccess=abs&issn=00157473&p=AONE&sw=w&userGroupName=anon%7Edf247dee

Zhang, J., Maupin, M. (2004). Face lateral and withdrawal resistances of staple joints in furniture-grade pine plywood. Forest Products Journal, 54(6), 40–46. http://kb.forestprod.org/Main/ind/?id=67119

https://doi.org/10.17306/mk.978-83-67112-51-2.6

Current situation of the Turkish furniture industry, global crises, and opportunities

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Keywords

Turkish furniture industry
global crises
global opportunities

Abstract

Furniture, which we encounter everywhere at home, at work, in the city, in the schools, in the hospitals, in the park, in the garden, is an inseparable part of human life and is with people, almost 24/7, wherever people are. The development of technology, the differentiation of design preferences and economic reasons cause significant changes in the materials used in the furniture production processes and on the final designs. Furniture is an important element for the people of our country and causes an increase in demand every day. Türkiye has a remarkable position in the field of furniture, both in its close geography and in the European Union. Of course, presently taking advantage for it is strategic location- is far below than what it should have been. Türkiye's young and dynamic population, entrepreneurial spirit, establishment of its industry on solid and well-established foundations, geographical and logistics advantages are the main factors in this. The Covid-19 pandemic, which emerged in December 2019 and affected the whole world suddenly and shockingly, affected the Turkish Furniture Industry as well as other countries and industries. Again, the logistics-container crisis that has emerged in the last few years has deeply affected world trade and all balances. In addition, the recent Russian-Ukrainian war has also had various effects on the industry. However, contrary to these negativities, the Turkish Furniture Industry has shown an unprecedented growth, high capacity utilization rates and export figures. This scientific study has manifested itself as a joint work of industry and non-governmental organizations. In this context, the current situation of the industry, capacity utilization, export/import figures, and changes in R&D (research & development), design and technological investment processes were examined.

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Introduction

The reports showing the annual import and export figures of the industries made by TURKSTAT gained greater importance with the pandemic outbreak in the last days of 2019. This is because the global pandemic affected all industries negatively and caused a serious contraction in the markets. In addition to the disruptions in imports and exports, the blockage in logistics channels and the container crisis that occurred in the middle of 2020 adversely affected the actors in the world markets.

According to the World Health Organization data, pneumonia cases detected in Wuhan, Hubei province in China in December 2019, were defined as the new coronavirus that has not been seen in humans before on January 5, 2020, as result of research. This virus, which emerged in China, spread all over the world in a short time of 3 months. In Türkiye, the first Covid-19 case was seen on March 11, 2020 (Budak and Korkmaz, 2020).

With the effect of the virus, the global recession in all industrial branches caused many brands to stop their activities in China. In this context, the fact that the decrease in China's production capacity could not meet the increasing global demand has led importers to search for different solutions. At this stage, the Turkish industry's high capacity, flexible structure, potential, cheap labor force, geographical advantage and low product costs due to the exchange rate enabled global importers to turn to Türkiye. In particular, the ready-made clothing, chemistry, automotive and food industries have taken rapid action in this regard, enabling global importers to turn their attention to Türkiye.

For the same reasons, the Turkish Furniture Industry has accelerated its export-oriented moves in order to get out of this crisis with the least damage. Considering the components of the furniture industry, it is observed that the supply and import of the sub-industry supporting this sector and therefore, supply and import of the raw materials have increased.

The wooden furniture and accessories industry has also followed a rising trend in the domestic market during the pandemic period. One of the most important reasons for this is that people are greatly restricted from going out, especially in certain periods, and therefore they tend to do modification or renovation works in the houses, which are the main living space, has given the industry a different momentum. The rapid increase in online sales channels, providing easier access to the products, also contributed to this development.

Another important reason for the excessive increase in demand is the inability of people to go to work, especially during the hardest period of the pandemic, the closure of workplaces and the development of the remote working model as a result of this. By the moment, the pandemic restrictions have eased, people can spend time comfortably at home and outside, and can easily go to their workplaces. However, the habit formed in a few years, the reaction of business life to remote work and the new system it has created continue people's desire to work from home after the pandemic. On the other hand, the fact that employees work from home during the pandemic has offered many advantages to workplaces. Saving of space/office, elimination or reduction of food-beverage and service costs are just one of them. People who started to work from home, on the other hand, had to move and set up the work order in their workplaces, as they did not have such an order before. For this reason, it became necessary to establish a new working model in a short time by installing computers and other technological tools and equipment in houses. Some continued to do this for their comfort. For all these reasons, there has been a serious demand burst in office furniture, which is an important sub-area of the furniture industry. In this context, the production and sales of tables, chairs, task chairs, libraries, etc. have increased. The fact that education was carried out from home for several years in the form of distance education has also increased the needs of students in this direction.

The spread of online sales has led to new and functional designs in packaged furniture products. It is seen that the designs made have brought different perspectives to the industry with the R&D studies made for special connections and equipment.

In addition, many fairs planned to be held in China in the field of fair organization could not be held. Türkiye has promoted Turkish products by inviting importers to its own national fairs in these areas. With it being an alternative for companies looking for new suppliers, an important opportunity has arisen in terms of Türkiye's exports. According to the research published by Financial Times, one of the world-famous newspapers, Türkiye was the only country that could be advantageous in terms of GDP (Gross Domestic Product) as a result of the decline in the growth rate due to the pandemic that emerged in Wuhan, China.

Export figures by years

With the outbreak of Covid-19, the uncertainty, especially in the early stages of the pandemic, caused the import and export of countries to pause around the world. The measures taken regarding the pandemic also negatively affected the global economy. In order to overcome this crisis with the least damage, all the countries of the world tried to find new supply areas by entering to different geographies for the supply of raw materials and products, as well as searching for new markets. In this context, many global manufacturers suspended their activities in China, causing the markets to shrink. With the efforts that can attract the increasing global demand to Türkiye in the short and medium term, this shrinkage in Asian markets has created an opportunity for Turkish exporters.

Interruptions in the supply chains of the world trade volume, along with problems in production inputs, decreased the world goods trade volume by 0.8% in the third quarter of 2021 (WTO, 2022).

Türkiye has a share of 0.21% from the world trade volume of approximately 20 trillion USD. In the table below, Türkiye's import and export figures and total trade between 2017 and 2021 are given. The foreign trade volume, which was 403 billion USD in 2017, decreased to 389 billion USD in 2020 with the outbreak of the pandemic. The trade routes opened in the field of logistics and supply as a result of the regression in the pandemic with the effect of the vaccine developed against Covid-19 have been a factor in the increase of Türkiye's foreign trade volume to 496 billion USD in 2021.

Table 1. Data of foreign trade by years

Years	Exports		Imports		Balance of foreign trade	Volume of foreign trade	Proportion of imports covered by exports (%)
	value	change (%)	value	change (%)	value		
2017	164 494 619	10.2	238 715 128	18.1	–74 220 509	403 209 747	68.9
2018	177 168 756	7.7	231 152 483	–3.2	–53 983 726	408 321 239	76.6
2019	180 832 722	2.1	210 345 203	–9.0	–29 512 481	391 177 924	06.0
2020	169 637 755	–6.2	219 516 807	4.4	–49 879 052	389 154 562	77.3
2021(r)	225 214 458	32.8	271 425 553	23.6	–46 211 095	496 640 011	83.0

Value: thousand US $.

Türkiye's exports in 2021 reached 225 billion USD, with an increase of 32.8% compared to the previous year. However, with the increase in imports by 23.6%, a foreign trade deficit of 46.2 billion USD was formed.

The increase in the trade volume, by entering new markets in industries that do not have a foreign trade deficit, positively affected the growth rate in GDP and brought it to 6% in 2020 (TİM, 2022).

Forest products industry export

All these data had reflections on both the general economy and the furniture industry. The changes in export records on an industrial basis, published every year by the Turkish Exporters Assembly (TIM), in 2019 and after, are as shown in the table below. Considering the analyzed export data of the furniture industry by years, a 25% increase was observed in 2021. Likewise, as of 2022, there is a 27% increase when compared to the first 7 months of the previous year. When the share of this increase in the furniture industry in total exports is analyzed together, it is seen that the share, which was 3.1% in 2019, increased to 3.3% in the first 7 months of 2022, resulting in an increase of 0.2 points.

Table 2. Sectoral export data for 2018–2021

Sector	Export Figures 1.000$ 1 January – 31 December									
	2018	2019	Change	Proportion (19)	2020	Change	Proportion (20)	2021	Change	Proportion (21)
Furniture paper forest products	5.014.621	5.529.995	10.3%	3.1%	5.566.505	0.7%	3.3%	6.993.833	25.6%	3.1%
General export total	176.860.826	180.468.488	2.0%	100%	169.514.167	6.1%		225.367.676	32.9%	32.9%

Table 3. 7-month export data for 2022

Sector	Export Figures 1.000$ 1 January – 31 July			
	2021	2022	change	proportion (22)
Furniture Paper Forest Products	3.713.600	4.728.598	27.3%	3.3%
General Export Total	121.235.504	144.416.688	19.1%	100%

As can be seen in the reports published periodically by the Turkish Exporters Assembly, the furniture industry, which is an important branch of the forest products industry, has succeeded in turning the economic contraction in the world to its advantage during the pandemic.

The important point to be noted here is that some of the inputs necessary for the formation of furniture were imported, so serious problems were experienced in the industry initially. Especially with the problems experienced in particleboard (chipboard) supply and the increase in export-oriented sales of domestic particleboard manufacturers, a major bottleneck has occurred in the domestic market. Turkish wood-based panels industry, which was operating at full capacity, then faced wood raw material problems, and the bottleneck could not be overcome for a long time due to the logistics problems when it came to solutions for the import of this product.

The shortage of containers in the field of logistics not only affected the imports and exports of countries negatively, but also caused disruptions in the manufacturing sector, and even a rapid increase in product prices, as access to raw materials became almost impossible.

In academic studies, 53% of the total expenses in furniture production are raw material expenses and 13.8% of the furniture production is wood-based panel products (Koç and Aksu, 1995).

With the investments it has made in the last 20–25 years, the Turkish wood-based panel industry is the 5th in the world and the largest producer in Europe, both in terms of technology and capacity. Here, in order to raise the industry to higher levels, it is necessary to solve the raw material problems permanently and to ensure a sustainable supply of quality raw materials. In this context, many different methods can be developed. The conversion of used furniture, the creation of fast-growing tree plantations can be listed as examples (Yildirim et al., 2014).

According to the research, in Europe, 49% of panel products such as MDF and HDF are used in furniture manufacture, 31% in parquet, 10% in construction industry and 9% in manufacture of doors. While particleboard is used in the furniture industry at a high rate of 82%, it is stated that 13% of it is used in construction and 3% is used in the manufacture of doors (İstek et al., 2017).

Since most of the plate industry manufacturing in Türkiye during the pandemic was directed to export, serious raw material shortages arose in the domestic market. The decrease in the supply to the market caused great increases in prices. With the reflection of this increase in raw materials on finished products, furniture prices increased more than expected. Thereupon, the Ministry of Commerce of the Republic of Türkiye imposed an export restriction on wood-based panel manufacturers in line with the decision taken in June 2021, and contributed to the solution of this problem by allowing the export of 20% of the production. However, as this was also found to be insufficient, the relevant state institutions decided to increase the quota in panel products as of April 13, 2022 and impose a 100% prohibition of export to provide all production to the domestic market. While the manufacturers of the panel industry objected to this decision, they showed the inadequacy of raw wood materials in Türkiye as the source of the main problem. Within the framework of these decisions, board exports decreased by 17% year-on-year (İlhan, 2022). Turkish Wood-Based Panel Association (YOMSAD), one of the most important non-governmental organizations in the industry, especially in solving the raw material problem, has made a serious effort and taken steps to solve this problem in coordination with many Ministries and their affiliates, especially the Ministry of Agriculture and Forestry, the General Directorate of Forestry.

In this situation, which seemed difficult to solve initially, measures have been taken to ensure that the relevant industry components come together and that the resources are procured with cooperation on a scaled scale. Thanks to these measures, the static furniture industry recovered in a short time and became able to respond to the demands.

Turkish Furniture Industry

Although the furniture industry has invested in technological machinery, mainly SMEs (Small and Medium-Sized Enterprises) have an important place in terms of employment. This makes Türkiye an important supplier for the European market, as labor costs are low compared to other exporting countries.

Considering the proportional distribution of furniture trade on the basis of countries across the world, in the light of the values given in Table 4, Türkiye has a share of 1.6% in exports and 0.2% in imports. While China ranks first in exports with a share of 32.8%, the USA has a 30% share in imports.

Table 4. Prominent Countries in Global Furniture Trade

Countries	Export (%)	Countries	Import (%)
China	32.8	USA	30.0
Germany	6.9	Germany	8.1
Poland	6.8	England	5.0
Vietnam	6.1	France	4.9
Italy	5.8	Canada	3.8
Mexico	4.1	Japan	3.8
USA	3.9	Holland	3.2
Türkiye	1.6	Türkiye	0.2

Source: Trademap.

When we look at the SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis of the Turkish furniture industry, its strengths include its competitive advantage, logistics infrastructure, being a developed industry with growth potential, and the fact that access to raw materials and workmanship can be solved with domestic resources at the level of 90%. In addition, factors such as the low number of integrated facilities, the capital problem of SMEs, the shortage of qualified technical personnel, and foreign dependency in production technologies constitute its weaknesses. The industry's intensive use of e-commerce channels in sales and marketing, price and quality advantage, and increasing foreign demand due to the desire of other countries to diversify China, which is the leading country in exports, constitute an opportunity for the industry. The most important threat is that China has become an aggressive player.

When all these are compared, it is seen with the increase in the export figures in the recent period that the furniture industry has made the right moves by combining the opportunities with its strengths. However, in order for the Turkish furniture industry to be able to do this much better, it needs to attach more importance to technology, R&D and innovation investments and to create unique designs with a competitive understanding in product design. Thus, the probability of getting a larger share from the world market will increase.

Conclusion and recommendations

The crisis that the world has experienced since the beginning of the pandemic has negatively affected the furniture industry on a global scale. However, this problem was quickly resolved with the search for different suppliers in a short time. In general, the Turkish furniture industry grew out of this crisis and became a sought-after actor in the market by expanding its market share. Of course, this is not enough, it should be able to do much better. In order to meet the demands for export, it needs to carry the developing technology and infrastructure to more advanced levels and create original and functional designs in the context of disassembled furniture.

In particular, the IKEA example, which can be formed by clustering abroad, and the creation of structures that are open to development and the quality of products and services that are systematically at the forefront will increase Türkiye's market share in the future.

Licensing and business establishment should be allowed after the companies established in the country are examined by the relevant authority with a feasibility report and whether they are suitable for competency in line with the requirement. Capital adequacy must be examined and a comparative analysis of the product to be produced, and the investment must be made.

On the other hand, factors leading to unfair competition with a small workshop and informal employment should be prevented. In order to prevent these problems, various regulations can be introduced in important parameters such as the size of workplaces, number of employees, capital adequacy. While doing this, the models of the United States of America, the European Union and China should be examined. Of course, every country has its own socioeconomic structure. Here, other countries should be considered and Türkiye's own parameters should be revealed with a scientific approach and common sense. It will be beneficial for company managers or owners to receive training on important issues such as investment, management of financial structure, borrowing. In fact, these can be in the form of professionally and institutionally certified trainings by making agreements with the Continuing Education Centers of the Universities. Thus, wrong money management and unnecessary investments in the industry can be minimized, efficiency can be increased with the correct use of scarce resources, and more competitive formations can be strengthened. Since the conscious producers will make the right investments for the development of their businesses, the export will also develop in parallel.

Of course, the development of the sector does not happen only with machinery and infrastructure investments alone. There is a need for human resources to use these sources, manage them and make the system sustainable. Universities and vocational high schools are needed in this respect. There is a shortage and need not only for engineers, industrial designers and architects but also for qualified intermediate staff graduated from vocational high schools/colleges more than ever.

There is no department in Türkiye directly for the furniture industry. In general, Woodworking Industrial Engineering, whose main field of activity is wood, and Forest Industrial Engineering Department graduates work in this industry. Since the industry is very wide, the courses in these departments also vary. This is both an advantage and a disadvantage. The graduate gains knowledge on many subjects little by little. However, in-depth expertise in a single field rather than little knowledge in many fields is a reason for preference in the furniture industry. Of course, it is not possible to expect the courses to be only furniture-oriented. For this reason, students are required to take common basic vocational courses in the first 2 years, and specialize in specific areas with the branching of the education in the 3rd and 4th years. Similar examples are available in other engineering departments at the leading universities in Türkiye. In these sections, topics such as furniture engineering, furniture components – materials, furniture design, surface chemicals, surface coatings can be highlighted in the branch to be created for the furniture industry. Thus, graduates who have high quality and in-depth knowledge can easily find job opportunities with improved personal rights, and they also add value to the companies they work for, and it is possible to produce more innovative and value-added products instead of just standing over the workers in those companies or maintaining the daily system.

The development of the wood-based panels industry, which is the main supplier of the furniture industry, in terms of both capacity and quality will have a positive impact on the results. It also has the environmental aspect. In Europe and the United States, there is a wide range of research and regulations. For example, the concepts of “European Green Deal”, “Circular Economy”, “Fit For 55” come to the fore. Used furniture or used wood and wood-based products in Türkiye can cause a big problem, especially in big cities. The visibility of the used and waste furniture in the streets is increasing day by day. This is not only environmental pollution, but also a great financial loss and a waste of resources. The Ministry of Environment, Urbanization and Climate Change of the Republic of Türkiye, the Ministry of Industry and Technology of the Republic of Türkiye, Governorships, Metropolitan Municipalities, District Municipalities, Universities, and non-governmental organizations operating in the field of forest products industry should come together to collect the used furniture or wood waste or urban transformation waste safely and recycle it into wood-based panels manufacture and should ensure that they are used in furniture production. Various certificates can be given to companies and their products in this context. Thus, the circular economy is supported.

References

Budak, F., Korkmaz, Ş. (2020). Covit-19 Pandemi Sürecine Yönelik Genel Bir Değerlendirme: Türkiye Örneği. Journal of Social Research and Management, 1, 62–79. https://doi.org/10.35375/sayod.738657

İlhan, L. (2022). Sektörler. Retrieved from Dünya: https://www.dunya.com/sektorler/mobilya/mdf-ve-yonga-levha-ihracati-yasaklandi-haberi-655467

İstek, A., Özlüsoylu, İ., Kızılkaya, A. (2017). Türkiye Ahşap Esaslı Levha Sektör Analizi. Bartın Orman Fakültesi Dergisi, 132–138. https://dergipark.org.tr/tr/pub/barofd/issue/27137/297231

Koç, H., Aksu, B. (1995). Küçük Ölçekli Bir Mobilya İşletmesinde Üretim Sürecinin Analizi,. İstanbul Üniversitesi Orman Fakültesi Dergisi, 79–89. https://avesis.iuc.edu.tr/yayin/827ccdd5-b183-48a3-a726-4ad5ab045cec/koc-k-h-aksu-b-1995-kucuk-olcekli-bir-mobilya-isletmesinde-uretim-surecinin-analizi-i-u-orman-fakultesi-dergisi-a-serisi-cilt-45-sayi-2-1995-s-79-91-yay-kom-sunulus-tarihi-27-02-1996

Novak, N., Krstulović-Opara, L., Ren, Z., Vesenjak, M. (2020). Mechanical properties of hybrid metamaterial with auxetic chiral cellular structure and silicon filler. Composite Structures, 234, 111718. https://doi.org/10.1016/j.compstruct.2019.111718

Smardzewski, J. (2015). Furniture design, 1st ed, Furniture Design. Springer International Publishing Switzerland, Heidelberg, New York, Dordrecht, London. Novak, N., Krstulović-Opara, L., Ren, Z., Vesenjak, M. (2020). Mechanical properties of hybrid metamaterial with auxetic chiral cellular structure and silicon filler. Composite Structures, 234, 111718. https://doi.org/10.1007/978-3-319-19533-9
TC. Kalkınma Bakanlığı (2019). Onbirinci Kalkınma Planı (2019–2023). Ankara: TC. Kalkınma Bakanlığı. https://www.sbb.gov.tr/wp-content/uploads/2022/07/On_Birinci_Kalkinma_Plani-2019-2023.pdf
TİM (2022). İhracat 2021 Raporu. Ankara: TİM. https://tim.org.tr/files/downloads/Strateji_Raporlari/TIM_Ihracat_2021_Raporu.pdf
TİM İhracatçılar Meclisi (2020). RCA 1000 Raporu. Ankara: TİM. https://tim.org.tr/files/downloads/Strateji_Raporlari/RCA_1000%20Raporu.pdf
WTO (2022, 08 23). 2021 news. Retrieved from World Trade Organization: https://www.wto.org/english/news_e/news21_e/stat_20dec21_e.htm
Yildirim, H.T., Candan, Z., Korkut, S. (2014). Wood-based panels industry in Türkiye: Future raw material challenges and suggestions. Maderas. Ciencia y tecnologia, 16(2), 175–186. http://dx.doi.org/10.4067/S0718-221X2014005000014

https://doi.org/10.17306/mk.978-83-67112-51-2.7

Machine selection for custom manufacturing in small-scale furniture businesses

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Keywords

machine choosing
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Abstract

With the integration of computer-aided design and computer-aided production, furniture industry enterprises seem to have problems such as not being able to fully use their existing production capacities and needing qualified personnel. In this context, the issue of machine selection for small-scale enterprises that make order-type production, based on the principle that a rational investment goes through the selection of the appropriate machine, has been examined. As it is known, unlike traditional machines, operators who will use CNC machines are expected to have basic CNC knowledge, at least enough PLC (Programmable Logic Controller) knowledge to change some settings, and the features of the machine they will use. In addition, the work to be done, the capacity of the enterprise, the desired quality from the product, the compatibility with other machines, the selection of machines that are not suitable for the production style, the presence of machines that cannot be used as they should and are kept in idle position to be evaluated in a different way cause great problems for the enterprise. Considering the intensity in our country, in this research, a small-capacity panel furniture manufacturer that makes order-type production is examined; machine types that stand out for three main processes such as panel sizing, edge banding and hole drilling are included. For this purpose, regardless of whether the panel furniture production is CNC, PLC controlled or conventional for the machine line, the machine type has been selected. In the study, AHP (Analytic Hierarchy Process), which is one of the multi-criteria decision making methods, was used as a method. As a result, suitable machine type or machine type combinations are suggested for small-scale furniture businesses.

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Introduction

It is seen that the woodworking machinery industry has largely completed the developments in woodworking and cutting theory, and continues its development with its integration with new technologies and informatics. In addition, with the integration of computer-aided design and production, furniture industry enterprises are generally faced with problems such as not being able to fully use their existing production capacities and needing qualified personnel. In this context, based on the principle that a rational investment goes through the selection of the appropriate machine, the issue of machine choosing for small-scale enterprises that make custom production is examined in this study. As it is known, unlike traditional machines, operators who will use CNC machines are expected to have basic CNC knowledge, at least enough PLC (Programmable Logic Controller) knowledge to change some settings, and the features of the machine they will use. However, the selection of machines that are not suitable for the work to be done, the capacity of the enterprise and the way of production, the presence of machines that cannot be used properly and kept in idle position to be evaluated in a different way cause great problems for the enterprise. This study was carried out on a small-capacity company, which is a panel furniture manufacturer, taking into account the density of furniture enterprises in our country, as well as the sectoral weight and production type, which is increasing in preference.

In the research, the selection of the machine type, which can be realized with CNC, PLC control or conventional, was made for the line of panel furniture production. Machine types such as panel sizing, edge tripling and hole drilling are included. This machine, CNC, PLC controlled or conventional production of panel furniture for the line, the machine type has been selected. Designed in this way, it is the design of models that are generally targeted in the design of suitable models of a machine type machine type for small-scale enterprises engaged in type production.

On the other hand, when the literature studies are examined, it is seen that the Turkish Woodworking Machinery sector has achieved a similar development in terms of technology, but is insufficient in terms of product-machine diversity and after-sales service (Investment-Production) support, considering the level of development in the world AIM sector. With this study, it is also aimed to contribute to the elimination of the sector's inadequacies in this area (Sofuoğlu and Kurtoğlu, 2013; Kurtoğlu and Dilik, 2018; 2021; Kuşcuoğlu, 2022).

Machine selection and effective factors in the furniture industry

As stated in the literature studies, in general, many factors are effective in machine selection. The common type of furniture in the furniture industry is panel furniture. Panel furniture is also called cabinet furniture or box furniture. Panel products such as particleboard, fiberboard, plywood, solid panel are used in the production of panel furniture. In the production of panel furniture, mass production type is generally used and the machines in the machine park are lined up and it is essential that the workpieces do not move backwards as much as possible. On the other hand, the increasing demand diversity with the developing technology increases the weight and importance of order type production in the furniture industry. In this context, the factors affecting the machine selection in general can be summarized as follows (Kobu, 2008; Kurtoğlu and Dilik, 2018; 2021; Sofuoğlu and Kurtoğlu, 2013; Kurtoğlu, 2010; Sofuoğlu, 2001).

1. Production type (series, custom, mixed etc.) and capacity
2. Types of products planned to be produced in the following periods
3. Compatibility of machines with each other in terms of capacity
4. Compatibility of machines with each other in terms of technology
5. Distance between machines, depending on part dimensions
6. Ease of repair, maintenance and use of machines
7. Price of machines
8. Working safety in machines
9. Benefit and cost analysis
10. Machine operator costs

With the developing technology, the rapid impact of both the changes in lifestyle and the trends that develop depending on the lifestyle on machine selection decisions, as in every field, is clearly seen from the literature studies. Today, due to the increase in consumer demands and competition conditions, enterprises engaged in mass production have begun to shape production conditions similar to custom production. This situation has increased the importance of the preparation times of the machines used in the furniture industry and has brought flexibility in production to the fore. In addition, one of the factors to be considered is production capacity. Optimum capacity values (İlhan and Burdurlu, 1993), which are determined depending on technical capacity, economic capacity, maximum capacity, actual capacity and intended production amount, play an important role in machine selection. Considering this situation from the furniture industry perspective, the prominent criteria when choosing a machine are factors such as price, ease of use, capacity, flexibility, processing quality and the area covered by the machine. Since a private enterprise was not focused on within the scope of the research, only the price, ease of use, capacity and flexibility factors were tried to be considered among all the criteria (Kurtoğlu and Dilik, 2021; Kuşcuoğlu, 2022).

Multi-criterative decision-making methods

Decision-making is the determination of the thought and action patterns applied in the necessary conditions and the selection of the most appropriate one in order to reach the desired goal. Having many alternatives in decision making and doubting which option should be chosen causes decision making problem. For this reason, in the solution of the decision-making problem, it is tried to solve the decision-making problem by paying attention to many criteria as stated below. These criteria are:

- what is the purpose,
- set target,
- environmental factors involved,
- state of the decision maker,
- alternatives,
- reaching the result.

It is specified in the form (URL 1).

Many classical or fuzzy logic-based methods are used by researchers in order to solve the problems known as multi-criteria decision making in the literature. These; Analytical Hierarchy Process (AHP), Analytical Network Process (AAS), MAUT, UTA, MACBETH, PROMETHEE, ELECTRE I-II-III, TOPSIS, UTADIS, FlowSort, GAIA and FS-Gaia (Uludağ and Doğan, 2016).

The AHP (Analytical Hierarchy Process) method, which is one of the multi-criteria decision-making methods in the research, was chosen because of its advantages such as providing significant convenience to users in terms of mathematical operations and intelligibility and the possibility of being used alone. In the study, the selection of the machine type, regardless of whether it is CNC, PLC controlled or conventional, is emphasized for panel sizing, edge banding and hole drilling, which are the three most important processes for the machine line of panel furniture manufacturing (URL1; Taş, 2010).

Methods and materials

Material

The research has been prepared on the companies operating in the field of panel furniture manufacturing, which produce in custom and mass production type.

In the study, machine selection is based on panel sizing, edge banding and hole drilling processes, which are known as the stages that are most exposed to bottleneck formation in furniture production. Different types of machines used in panel sizing, edge banding and hole drilling are handled over different capacities.

Method

In the research, AHP (Analytical Hierarchy Process) method, which is one of the multi-criteria decision-making methods, was applied due to its advantages. For this purpose, the values in the pairwise comparison scoring used in the created matrices and their equivalents are shown in Table 1 (URL 2).

Table 1. Scoring scale table

Importance values	Value vefinitions
1	Equal importance
3	A little more important (less superiority)
5	Quite important (too superior)
7	Very important (very superior)
9	Extremely important (absolute superiority)
2, 4, 6 and 8	Intermediate values (compromise values)

In the study, machine selection application was made for 3 basic production processes (panel sizing, edge banding, hole drilling) for small-scale enterprises that make custom production. For this purpose, the following scenarios were created for each production process and it was tried to reach the appropriate machine selection decisions.

Scenario 1: Custom production, panel sizing, up to 50 sheets.

Scenario 2: Custom production, edge banding, up to 1600 meters.

Scenario 3: Custom production, drilling, up to 600 surfaces.

From small-scale enterprises to large-scale enterprises, there are different capacities for each process, and in the creation of scenarios; Production types, processes and capacities were blended separately and the selection of the appropriate machine was determined based on comparison matrices. As a result, four different comparison criteria were determined as price, capacity, ease of use and flexibility.

For each case, for example; A company that produces to order type, up to 50 wooden boards per day, while making panel sizing machine comparisons, 4 different matrices in total were created for each of the criteria of "Price", "Space Covered by the Machine", "Capacity" and "Ease of Use". At the same time. In order to determine the advantages of the determined criteria among themselves, the criteria matrix application was made.

Results and discussion

In the study, the comparison matrices and results obtained for machine selection for the 3 basic production processes (panel sizing, edge banding, hole drilling) are given below for each scenario.

The normalization matrix for the criteria determined for Scenario 1 (panel sizing process) has emerged as shown in Table 2.

Table 2. Criteria and normalization matrix for scenario 1

Normalization matrix (criteria)	Price	Capasity	Ease of use	Flexibility	Weight (W)	V	V/W
Price	0.0556	0.0556	0.0333	0.0714	0.0540	0.2168	4.0168
Capacity	0.0556	0.0556	0.0333	0.0714	0.0540	0.2168	4.0168
Ease of use	0.3889	0.3889	0.2333	0.2143	0.3063	1.2571	4.1036
Flexibility	0.5000	0.5000	0.7000	0.6429	0.5857	2.4762	4.2276
					1.0000		4.0912
CI	0.030406889						
RI	0.882						
CR	CI/RI = 0.0345						

As seen in Table 2, the "CR" value was found below 0.1. Calculations appear to be consistent.

The decision matrix for scenario 1 was determined as given in Table 3.

Table 3. Decision matrix for scenario 1

Decision matrix (Scenario 1)	Price	Capacity		Ease of use	Flexibility		Criteria		Result
VS	4.2222	4.0151		4.0408	4.0408		4.0168		66.7528
VS+HS	4.1747	4.0395		4.0362	4.0362	X	4.0168	=	66.6214
CNCB	4.0362	4.0802		4.2222	4.1747		4.1036		67.5773
CNCB+HS	4.0408	4.0395		4.1747	4.2222		4.2276		67.4382

VS : Vertical Sizing Machine
VS+HS : Vertical Sizing+Horizontal Circular Saw Machine
CNCB : CNC Wooden Panel Machining Center (ACCEPTED)
CNCB+HS : CNC Wooden Panel Machining Center+ Horizontal Circular Saw Machine

As a result, when the decision matrix of Scenario 1 is examined, it is seen that CNCB (CNC Wood Board Machining Center with Large Table) stands out with a score of 67,5773 (Fig. 1). CNCB+HS (CNC Wooden Panel Machining Center and Horizontal Circular Saw Machine) took the second place.

Fig. 1. CNC Wooden Panel Machining Center (URL 3)

The criteria and normalization matrix determined for Scenario 2 (Edge Banding Process) appeared as given in Table 4.

Table 4. Criteria and normalization matrix for Scenario 2

Normalization Matrix (criteria)	Price	Capacity	Ease of use	Flexibility	Weight (W)	V	V/W
Price	0.1071	0.1875	0.0735	0.1193	0.1219	0.4919	4.0362
Capacity	0.0357	0.0625	0.0441	0.0852	0.0569	0.2299	4.0408
Ease Of Use	0.3214	0.3125	0.2206	0.1989	0.2633	1.0994	4.1747
Flexibility	0.5357	0.4375	0.6618	0.5966	0.5579	2.3555	4.2222
					1.0000		4.1185
CI	0.039488555						
RI	0.882						
CR	CI/RI = 0.0448						

The decision matrix of scenario 2 has emerged as given in Table 5.

Table 5. Decision matrix for Scenario 2

Decision matrix (Scenario 2)	Price	Capacity	Ease of use	Flexibility		Criteria		Result
EB8	4.2222	4.0408	4.0362	4.0362		4.0362		67.2611
EB14	4.1747	4.0362	4.2222	4.2222	X	4.0408	=	68.6123
EB20	4.0362	4.1747	4.1747	4.1747		4.1747		68.2139
EB20U	4.0408	4.2222	4.0408	4.0408		4.2222		67.3008

EB8 : Single-Sided Edge Banding (≤ 8 m/min)
EB14 : Single-Sided Edge Banding (≤ 14 m/min) (ACCEPTED)
EB20 : Single-Sided Edge Banding (≤ 20 m/min)
EB20U : Single-Sided Edge Banding (> 20 m/min)

Fig. 2. Single-sided Edge Banding Machine (URL 4)

For the edge banding process, the result from Table 5 (Figure 2) has been determined as the suitability of the „Single-Sided Edge Banding Machine" with a feed rate of 14 m/min or less.

The criteria and normalization matrix determined for Scenario 3 (Hole Drilling Process) appeared as given in Table 6. Hole density, which is an important parameter in drilling processes (such as what type and how many holes will be drilled on a surface) has not been taken into account. However, depending on the nature of the production, in some cases, holes are drilled not only on one surface but on more than one surface, so the selection of the machine is based on the number of surfaces, not the parts. In the drilling process, which is the last process of order type production, in some cases, since the hole is not drilled on only one surface, it is not the number of pieces but the number of surfaces.

Table 6. Normalization matrix of criteria determined for Scenario 3

Normalization matrix (criteria)	Price	Capacity	Ease of use	Flexibility	Weight (W)	V	V/W
Price	0.1000	0.1000	0.1154	0.0714	0.0967	0.3883	4.0152
Capacity	0.1000	0.1000	0.1154	0.0714	0.0967	0.3883	4.0152
Ease of use	0.5000	0.5000	0.5769	0.6429	0.5549	2.2769	4.1030
Flexibility	0.3000	0.3000	0.1923	0.2143	0.2516	1.0168	4.0408
					1.0000		4.0435
CI	0.01450252						
RI	0.882						
CR	CI/RI=0.0164						

The decision matrix for Scenario 3 was also determined, as shown in Table 7.

Table 7. Decision matrix for Scenario 3

Decision matrix (Scenario 3)	Price	Capacity	Ease of use	Flexibility		Criteria		Result
12V	4.0802	4.0177	4.0177	4.0430		4.0152		65.3356
CNCB	4.0395	4.0781	4.1807	4.2760	X	4.0152	=	67.0251
CNCB+12V	4.0151	4.1807	4.0781	4.3043		4.1030		67.0325
MMD	4.0395	4.0177	4.0177	4.0755		4.0408		65.3034

12V : Drilling machine with 1 horizontal, 2 vertical heads
CNCB : CNC Wooden Panel Machining Center
CNCB+12V : CNC Wooden Panel Machining Center+Drilling Machine. 1 horizontal., 2 Vertical Heads (ACCEPTED)
MMD : Manual Multi Hole Drilling Machine

Fig. 3. CNC Wooden Panel Machining Center and Multi-Hole Drilling Machine with 1 Horizontal and 2 Vertical Heads (URL 1, URL 5)

According to these results in Table 7, the combination of "CNC Wooden Panel Machining Center" and "Multi Hole Drilling Machine with 1 Horizontal, 2 Vertical Heads" (CNCB + 12D) (Fig. 3) emerged as the most suitable machine option for Scenario 3 (hole drilling process).

Conclusions

Among the alternative machine options for the production processes examined in the research, the most suitable machine option was determined as follows.

For Scenario 1 (Panel Sizing Process) for producers with a production capacity of up to 50 plates; Vertical Sizing Machine, Vertical Sizing Machine + Reclining Circular Saw Machine Combination, CNC Wooden Panel Machining Center etc. among the alternative machines, it has been revealed that the most suitable one is the “CNC Wooden Panel Machining Center (CNCB)”.

For Scenario 2 (Edge Banding Process) for producers using edge bands up to 1600 meters per day, making custom production; Single-Sided Edgebander (up to 8 m/min), Single-Sided-Edgebander (up to 14 m/min), Single-Sided Edgebander (up to 20 m/min), Single-Sided Edgebander (over 20 m/min) etc. It turned out that the most suitable one among the alternative machines is the “Single-Sided Edge Banding Machine” with a feeding speed of 14 m/min or less, with the code EB14.

In the hole drilling process, depending on the nature of the production, in some cases, since holes are drilled not only on one surface but on more than one surface, the machine is chosen based on the number of surfaces, not the piece. For Scenario 3 (Hole Drilling Process) for working situations with a daily drilling capacity of up to 600 surfaces in custom production; there are machine alternatives such as 1 Horizontal 2 Vertical Head Drilling Machine, CNC Wooden Panel Machining Center, CNC Wooden Panel Machining Center + 1 Horizontal 2 Vertical Head Drilling Machine Combination, Manual Multi Hole Drilling Machine etc. in the study, the combination of “CNC Wooden Panel Machining Center” and “Drilling Machine with 1 Horizontal 2 Vertical Heads” (CNCB + 12 V) turned out to be the most suitable for this purpose.

References

İlhan, R., Burdurlu, E. (1993). Factory planning in the woodworking industry. Ankara.

Kobu, B. (2017). Production management. Beta Yayıncılık: Istanbul.

Kurtoğlu, A. (2010). Woodworking techniques and machines lecture notes (Unpublished). Istanbul University, Fachulty of Forestry, Department of Forest Industrial Engineering.

Kurtoğlu, A., Dilik, T. (2018). Furniture and wood constructions lecture notes (Unpublished). Istanbul University-Cerrahpasa Faculty of Forestry, Department of Forest Industrial Engineering.

Kurtoğlu, A., Dilik, T. (2021). Furniture industry lecture note (Unpublished). Istanbul University-Cerrahpasa Faculty of Forestry, Department of Forest Industrial Engineering.

Kuşcuoğlu, M.Ö. (2022). The sector of turkish woodworking machine in the process of EU. Istanbul University – Cerrahpasa, Institute of Graduate Studies, Department of Forest Industry Engineering, PhD thesis.
Sofuoğlu, S.D. (2001). The surveys for determination of the westage rates at massive wood material processing, Msc. thesis. Istanbul University, Institute of Science, Department of Forest Industrial Engineering.
Sofuoğlu, S.D., Kurtoğlu, A. (2013). The wastage rates at massive wood material processing. Journal of Science and Technology of Dumlupinar University, 11, 189–204. https://www.researchgate.net/publication/262672554_The_Wastage_Rates_at_Massive_Wood_Material_Processing
Taş, Y. (2010). Application of failure mode and effects analysis (FMEA). Technique to Furniture Industry. Msc. thesis. Istanbul University, Instıtute of Science, Department of Forest Industrial Engineering.
Uludağ, A.S., Doğan, H. (2016). A service quality application focused on comparison of multi-criteria decision making methods. Çankırı Karatekin University Journal of The Faculty of Economics and Administrative Sciences, 6(2), 17–47. https://dergipark.org.tr/tr/pub/ckuiibfd/issue/32908/365616
URL 1. https://www.iienstitu.com/blog/karar-verme-teknikleri-nelerdir (Accessed 06.06.21).
URL 2. https://thegemba.org/analitik-hiyerarsi-sureci-ahs-ahs/ (Accessed 04.10.22).
URL 3. https://ormendmakina.com/urun/krc-fantom-serisi/ (Accessed 08.04.22).
URL 4. https://ormendmakina.com/urun/casadei-flexa-47/ (Accessed 08.04.22).
URL 5. https://ormendmakina.com/urun/maggi-boring-system-323-3-kafa/ (Accessed 08.04.22).

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Effective factors in the selection of furniture hardware and alternative approaches on preference priority

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Keywords

furniture hardware
hinge system
drawer system
lift-up door system

Abstract

As can be seen from the developments in the world furniture sector, in this study, the selection and use of furniture hardware, which play an important role in providing a competitive advantage in both the production and marketing of furniture, are examined, the important factors in the selection of furniture hardware are determined and their effects on the priority of preference are tried to be revealed. In this context, a survey study was conducted on small and medium-sized businesses to determine the effects of the factors that are important in selecting hardware on the preference priority. In determining the effects on preference priority, an evaluation method was followed based on the nature of the enterprises (being a manufacturer or supplier) and the status of the hardware on a product basis. As a result, it has been determined that the product-based features of the hardware differ with the structural nature of the enterprises in the preference priority in the selection and use of hardware. In this framework, alternative approach suggestions have been developed for the furniture industry for the choice of hardware.

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Introduction

As can be seen from the developments in the world furniture sector, in this study, the selection and use of furniture accessories, which play an important role in providing a competitive advantage in both the production and marketing of furniture, are examined, the important factors in the selection of furniture accessories are determined, and their effects on the preference priority are tried to be revealed. This study is based on the M.Sc. titled "The importance of hardware in furniture production and determination of the criteria in the selection of furniture hardware", conducted at Istanbul University-Cerrahpasa Institute of Graduate Studies Department of Forest Industry Engineering.

Prepared using thesis data furniture accessories, which gain more and more importance in the furniture industry with the effect of global trends, play an important role in increasing the added value by contributing to the furniture's originality, functionality and aesthetic features. On the other hand, as can be clearly seen from the developments in the world furniture market and literature studies, the selection and use of furniture accessories emerge as the most important factor in providing competitive advantage. For example, a piece of furniture can be presented to the market as a new model and design by changing only one accessory (Dilik and Erdinler, 2003; Kılıç, 2021; Kurtoğlu and Dilik, 2020).

In terms of the research subject (production, marketing, materials, standardization-measures, variety, etc.), it consists of a very wide field of study, and the scope of the study is limited due to the method to be applied in the research. The scope of the study is limited to the determination of user and producer-oriented criteria in the selection of accessories for furniture and the development of proposals to increase the level of international competition in this field.. Considering the development level of the world accessory market, the furniture accessories industry in our country provides a similar development in terms of technological development, but it is insufficient in terms of product diversity. This situation emerges as an important constraint in the selection of accessories for both the user and the manufacturer. On the other hand, the differentiations in the changing lifestyle with the developing technology are rapidly changing the expectations from the furniture used in all areas of daily life. We can summarize the main effects of the trends that develop depending on the lifestyle on the furniture industry as follows. (Kurtoğlu and Dilik, 2019).

- The birth and spread of modern electro-furniture equipped with technology as a necessity of modern life.
- With the effects of smart housing and green building formations, smart furniture and environmentally friendly furniture applications are more common.
- The rapid increase in the share of modular furniture in the world market, which increases the quality of life, provides ease of use, is human and environmentally friendly, light, functional, easily portable, depending on the understanding of urbanization and rapidly increasing housing.
- More involvement of suppliers in the design process, suppliers with different fields of expertise (such as furniture, electronics, information technology, accessories, etc.) gaining importance.
- Increasing importance of furniture waste with the recycling issue.

As a result of the reflection of nanotechnology applications on the material, the use of dirt and stain-proof fabrics, leathers, environmentally friendly sponges, paints and varnishes is rapidly becoming widespread.

Classification of furniture accessories

It is seen that the classification for the accessory sector, which is expanding its product range day by day, was made by Dilik (1992) for the first time in our country, as shown in Table 1. However, apart from this classification, it is seen that today, for this purpose, most accessory manufacturers prefer catalog studies that introduce their product ranges by making a classification that groups different models of the product groups belonging to the same product. It is possible to say that this is one of the main problems in collecting sectoral data and reaching accurate statistical information.

Table 1. Classification of Furniture Accessories (Dilik, 1992)

Accessory group	Varieties
1 – Hinges	a) door and window hinges b) furniture hinges
2 – Door, window and furniture sliding sets	a) slides and rollers b) chains, scissors, stoppers
3 – Handles	a) door and window handles b) furniture handles
4 – Closing devices (lock, latch and keys)	a) door locks and latches b) window locks and latches c) furniture locks and latches
5 – Fixing and connecting elements	a) wood screws, nails and bolts b) plastic fasteners c) pullers d) corner bar and reinforcement elements
6 – Underfoot mechanism	a) castors, roulette and balls b) capsules, hobnails and bracelets c) base legs etc. underfoot mechanisms
7 – Other accessories and equipment	a) capsules, pins b) snaps, clips c) hanger elements d) hooks

General Factors Affecting The Selection of Furniture Accessories

Based on the literature studies examined within the scope of the research, the general factors affecting the selection of furniture accessories were determined as shown in Table 2 (Kılıç, 2021; Kurtoğlu and Dilik, 2020; Url 1; Url 2; Url 3; Url 4; Url 5; Url 6).

Table 2. General factors affecting furniture accessory selection (Kılıç, 2021)

1. Brand awareness
2. Affordability
3. Furniture type
4. Quality certificates
5. Furniture trend
6. Supply chain management
7. Warranty period
8. Loading capacity
9. Delivery time
10. Color
11. Integration program used

Product-based factors affecting the selection of furniture accessories

For this purpose, the factors that are effective on the product basis in the selection of furniture accessories examined within the scope of the research were determined as shown in Table 3, based on the technical specifications specified and recommended by the accessory manufacturers.

These factors have been tried to be explained by classifying them for 3 different product groups as Hinge Systems, Door Systems and Drawer Systems (Url 1; Url 2; Url 3; Url 4; Url 5; Url 6).

Table 3. Factors affecting furniture selection on a product basis (Kılıç, 2021)

A. Factors affecting hinge selection	B. Factors affecting the choice of lift-up door system	C. Factors affecting the choice of drawer systems
1. Door weight	1. Door weight	1. Drawer opening type
2. Door tyhickness	2. Cabinet body depth	2. Loading capacity
3. Soft closing effect and structure	3. Door opening type	3. Mounting type
4. Hinge opening angle	4. Function type	4. Function type
5. Door opening angle	5. Electrical opening assist	5. Color
6. Handleless door usage	6. Adjustment feature	6. Side wall thickness
7. Overlay distance	7. Easy assembling	7. Type of machine used
8. Color	8. Packing type	8. Place of use
9. Hinge drilling machine axis spacing	9. Color	9. Coating type
10. Type of machine used		10. Adjustment feature
11. Mounting plate type		11. Metal side height
12. Adjustment feature		12. Cabinet body design
13. Type of packaging		
14. Cabinet body design		

Methods and materials

The subject of this research is the examination of the factors affecting the selection of furniture accessories, which have an impact in every field, from the design of the furniture to the production, from the functionality to the marketing, and the examination of alternative approaches to determine their effects on preference priority. In this context, the data of the Master's thesis on Istanbul-Modoko Industrial Zone companies have been evaluated, taking into account both their production capacity and market shares, in order to ensure that they represent the accessory industry to a large extent. 163 out of 350 registered companies participated in this thesis study, which was carried out in Modoko Industrial Site, which includes many companies that produce furniture in every style (classic-modern) and make custom designs.

The survey content applied in the study was planned to determine the factors affecting the selection of accessories, both in general and on a product basis, and it was aimed to reveal the effects of the structural features and activity areas of the enterprises on these factors. In the analysis of the findings obtained in this context, the statistical package program SPSS 25.0 was used. In order to determine the level of difference between the groups in the analysis of the data, the Kruskal Wallis test was applied because the dependent variable was at the classification level. The results were evaluated with a 95% confidence interval and a significance level of $p < 0.5$.

Results and discussion

Findings on the structural features of the businesses participating in the research

The distribution of the enterprises participating in the survey applied in the research, according to their fields of activity, was determined as shown in Table 4. Accordingly, 63.2% of the companies are manufacturers, 27% are manufacturers and suppliers, and 9.8% are suppliers.

Table 4. Examining the distribution of companies in their fields of activity (Kılıç, 2021)

Area of activity	Number (N)	Percent (%)
Manufacturer	103	63.2
Supplier	16	9.8
Manufacturer and	44	27.0
Total	163	100

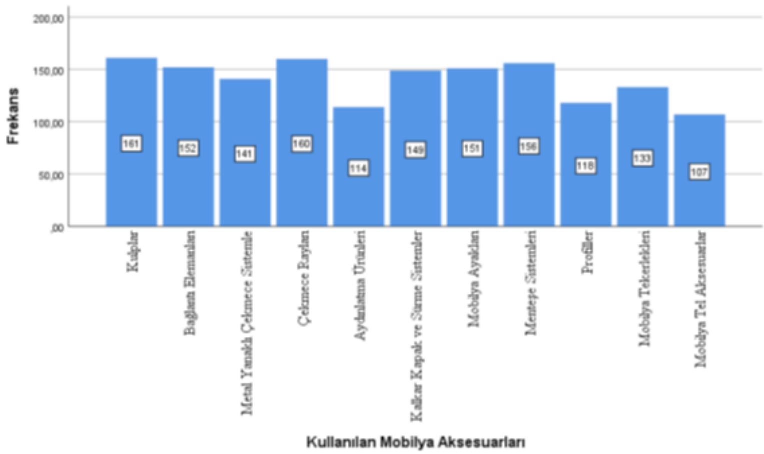

Fig. 1. Distribution of accessories used by companies in furniture (Kılıç, 2021)

As stated in the literature research, it is seen that furniture accessories have a wide variety of types and models, and this product range is increasing day by day. In the research, within the scope of the question asked to determine the most used furniture accessories in furniture, the most used accessories and their distribution ratios were determined as shown in Fig. 1. Accordingly, the most used and prominent accessories by furniture companies are respectively; Handles (10.4%), drawer slides (10.3%), hinge systems (10.1%), connecting fittings (9.9%), furniture legs (9.8%), lift and sliding systems (9.7%), profiles (7.7%), lighting products (7.4%), furniture wire accessories (6.9%) and furniture wheels (5.6%).

Findings on factors in general impact on accessory selection

For this purpose, the companies participating in the survey were classified according to their fields of activity and evaluated separately.

The distribution ratios of the importance levels of the expectations of the companies that participated in the research and whose field of activity is manufacturer, from furniture accessories were determined as shown in Table 5. Accordingly, a large part of the manufacturing companies are "Lifetime and warranty period" (44.7%), "Originality and image" (39.8%), "Price" (38.8%), "Functionality" (36.9%), "Aesthetic properties" (32%) stated their expectations as the most important. A large part (25.2%) stated that it is important to the expectation level of the manufacturers, whether it is imported or domestic.

Table 5. Distribution of importance levels for manufacturers' expectations from accessories (%) (Kılıç, 2021)

Factors	Most important	Important	Sufficient	Medium	Insignificant	Very unimportant	Total
Price *n*	40 38.8	22 21.4	7 6.8	5 4.9	8 7.8	21 20.4	103 100.0
Functionality *n*	38 36.9	22 21.4	10 9.7	4 3.9	16 15.5	13 12.6	103 100.0
Aesthetic *n*	33 32.0	15 14.6	15 14.6	21 20.4	9 8.7	10 9.7	103 100.0
Life and warranty period factor *n*	46 44.7	22 21.4	8 7.8	8 7.8	10 9.7	9 8.7	103 100.0
Imported or local product status	25 24.3	26 25.2	17 16.5	7 6.8	13 12.6	15 14.6	103 100.0
Originality and image *n*	41 39.8	18 17.5	11 10.7	5 4.9	12 11.7	16 15.5	103 100.0

The distribution ratios of the importance levels of the expectations from the furniture accessories of the suppliers, which are the field of activity in the research, were determined as shown in Table 6. Accordingly, most of the supplier companies expect "Originality and image" (49.8%), "Aesthetic properties" (43.8%), "Price" (37.5%), "Functionality" (37.5%), "Imported or local product status" (37.5%) as the most important factors. It is seen that the level of expectation for the service life and warranty period factor is stated as the most important and very unimportant by a large part of the companies (37.5%).

Table 6. Distribution of importance levels for the expectations of suppliers from accessories (%) (Kılıç, 2021)

Factors	Most Important	Important	Sufficient	Medium	Insignificant	Very unimportant	Total
Price *n*	6 37.5	1 6.3	2 12.5	1 6.3	1 6.3	5 31.3	16 100.0
Functionality *n*	6 37.5	2 12.5	– –	2 12.5	2 12.5	4 25.0	16 100.0
Aesthetic properties *n*	7 43.8	– –	3 18.8	– –	2 12.5	4 25.0	16 100.0
Life and warranty period factor	6 37.5	2 12.5	1 6.3	1 6.3	– –	6 37.5	16 100.0
Imported or local product status	6 37.5	5 31.3	1 6.3	– –	1 6.3	3 18.8	16 100.0
Originality and image *n*	8 49.8	3 18.8	1 6.3	– –	1 6.3	3 18.8	16 100.0

The distribution ratios of the importance levels of the expectations from the accessories of the enterprises, whose field of activity in the research is both manufacturer and supplier, were determined as shown in Table 7. Accordingly, the importance levels of these companies' expectations from accessories are respectively; "Originality and image" (40.9%), "Functionality" (38.6%), "Aesthetic properties" (36.4%), "Lifetime and warranty period" (36.4%), "Imported or local product status" (34.1%), "Price" (29.5%).

Table 7. Distribution of importance levels for the expectations of manufacturers and suppliers from accessories (%) (Kılıç, 2021)

Factors	Most important	Important	Sufficient	Medium	Insignificant	Very unimportant	Total
Price *n*	13 29.5	9 20.5	5 11.4	2 4.5	3 6.8	12 27.3	44 100.0
Functionality *n*	17 38.6	7 15.9	2 4.5	2 4.5	5 11.4	11 25.0	44 100.0
Aesthetic properties *n*	16 36.4	4 9.1	5 11.4	3 6.8	3 6.8	13 29.5	44 100.0
life and warranty period factor	16 36.4	5 11.4	3 6.8	5 11.4	3 6.8	12 27.3	44 100.0
Imported or local product status	15 34.1	4 9.1	3 6.8	7 15.9	5 11.4	10 22.7	44 100.0
Originality and image *n*	18 40.9	5 11.4	– –	3 6.8	2 4.5	16 36.4	44 100.0

Findings on factors in product basis on accessory selection

In the research, it has been tried to determine whether the demand of the furniture sector from the accessory sector in terms of product group and variety is met at sufficient quality and quantity.

For this purpose, the factors affecting the selection of accessories on a product basis; It has been determined over 3 different accessory groups selected as Hinge systems, Drawer systems and Lift-Up door systems.

The findings obtained in this context are shown in Table 8. Accordingly, the rates of meeting the sectoral demand at a sufficient quality level were determined as "very good" in Drawer systems (77.9%), Hinge systems (76.1%) and Lift Up Door systems (62%).

In the research, the findings regarding the situation of meeting the sectoral demand in quantity (quantity) are shown in Table 9. Accordingly, the ratios of meeting the sectoral demand in terms of quantity (quantity) were determined as "very good" in Drawer systems (76.7%), Hinge systems (76.7%) and Lift up Door systems (66.9%).

Table 8. The ratio and distribution of the companies' demand from the accessory sector at a sufficient quality level on a product basis (Kılıç, 2021)

Quality	Hinge system		Drawer system		Door system	
	n	%	*n*	%	n	%
Very bad	–	–	–	–	1	0.6
Bad	–	–	1	0.6	8	4.9
Neutral	6	3.7	9	5.5	14	8.6
Good	33	20.2	26	16.0	39	23.9
Very good	124	76.1	127	77.9	101	62.0
Toplam	163	100.0	163	100.0	163	100.0

Table 9. The ratio and distribution of the companies' demand from the accessory sector in terms of quantity (quantitative) on a product basis (Kılıç, 2021)

Quality	Hinge system		Drawer system		Door system	
	N	%	N	%	N	%
Very bad	–	–	–	–	–	–
Bad	2	1.2	1	0.6	5	3.1
Neutral	5	3.1	5	3.1	10	6.1
Good	31	19.0	32	19.6	39	23.9
Very good	125	76.7	125	76.7	109	66.9
Toplam	163	100.0	163	100.0	163	100.0

Findings on the effect of business activity field on accessory selection

In the research, the findings obtained to reveal the effects of the enterprises' structural features and activity areas on the factors affecting the selection of accessories are shown in Table 10.

businesses according to their fields of activity, classified according to their status as manufacturer, supplier and both manufacturer and supplier. In this context, the data obtained on the factors affecting the selection of accessories are shown in a comparative manner.

When Table 10 is examined, it has been revealed that the importance levels of the business activity area on the factors affecting the selection of accessories differ. For example; While there is no significant difference in terms of brand awareness, economy, furniture type, quality certificates, furniture trend, Supply Chain Management, warranty period, Loading capacity, delivery time and color factors according to the fields of activity, it has been revealed that there are significant differences according to the fields of activity of the companies in the integration program used.

Table 10. Comparison of the effect of the business field of activity on the factors affecting the selection of accessories and their importance levels (Kılıç, 2021)

Factors affecting the selection	Activity class	*n*	Class average	X^2	*sd*	*P*
Brand awareness	– manufacturer	103	77.41	4.350	2	0.114
	– supplier	16	92.78			
	– manufacturer and supplier	44	88.83			
Economy	– manufacturer	103	81.95	0.231	2	0.891
	– supplier	16	77.81			
	– manufacturer and supplier	44	83.64			
Furniture type	– manufacturer	103	78.79	4.118	2	0.128
	– supplier	16	73.38			
	– manufacturer and supplier	44	92.65			
Quality certificates	– manufacturer	103	79.67	1.991	2	0.370
	– supplier	16	77.25			
	– manufacturer and supplier	44	89.18			
Furniture trend	– manufacturer	103	79.31	2.378	2	0.305
	– supplier	16	76.50			
	– manufacturer and supplier	44	90.31			
Supply chain management	– manufacturer	103	82.34	1.064	2	0.587
	– supplier	16	72.66			
	– manufacturer and supplier	44	84.60			
Warranty period	– manufacturer	103	80.85	0.477	2	0.788
	– supplier	16	79.63			
	– manufacturer and supplier	44	85.56			
Loading capacity	– manufacturer	103	78.53	5.220	2	0.074
	– supplier	16	70.16			
	– manufacturer and supplier	44	94.42			
Delivery time	– manufacturer	103	83.80	2.625	2	0.269
	– supplier	16	65.41			
	– manufacturer and supplier	44	83.82			
Colour	– manufacturer	103	79.46	1.078	2	0.583
	– supplier	16	90.59			
	– manufacturer and supplier	44	84.82			
Integration program used	– manufacturer	103	75.74	7.024	2	0.030*
	– supplier	16	81.44			
	– manufacturer and supplier	44	96.86			

Conclusions

As a result, it has been revealed that the importance levels of the factors affecting the selection of furniture accessories with a wide variety and wide product range differ. It is seen that the main reasons for these differences are the effect of world furniture trends, the technological features of accessories on a product basis, and the increasing variety of types and models. In addition, it is seen that the structural feature of the enterprise and the field of activity affect the importance levels of the factors affecting the selection of accessories.

Within the scope of the research, the general factors affecting the selection of accessories; 1. Brand Awareness, 2. Affordability, 3. Furniture Type, 4. Quality Certificates, 5. Furniture Trend, 6. Supply Chain Management, 7. Warranty Period, 8. Loading Capacity, 9. Delivery Time, 10. Color, 11. It has been determined as the Integration Program used. It has been determined that the importance levels of these factors in the selection of accessories vary according to the accessory type and product group. For example; While the factor of "Use life and warranty period" (44.7%) takes the first place in the ranking of the expectations and importance levels of the enterprises in the field of activity, in the selection of accessories, the first place in the expectation and importance levels of the enterprises in the position of Supplier in the selection of accessories is "Originality and image" (56%). It turns out that the factor, 3) is taking.

The factors affecting the selection of accessories on a product basis were determined as follows over 3 different product groups selected. It has been revealed that the importance levels and orders of these factors vary according to the field of activity of the enterprises, as in the general factors.

A. Factors affecting the selection of hinge systems:

1. Door weight, 2. Door thickness, 3. Braking effect and structure, 4. Hinge opening angle, 5. Door opening angle, 6. Handleless door usage, 7. Overlap distance, 8. Color, 9. Hinge drilling machine axis range, 10. Machine type used, 11. Mounting type, 12. Adjustment feature, 13. Packing type

B. Factors affecting the selection of drawer systems:

1. Drawer opening type, 2. Loading capacity, 3. Assembly type, 4. Function type, 5. Color, 6. Wood thickness, 7. Machine type used, 8. Place of use, 9. Coating type, 10. Adjustment feature, 11. Metal sidewall height, 12. Cabinet body design

C. Factors affecting the selection of Lift-Up Door Systems:

1. Door weight, 2. Cabinet body depth, 3. Door opening type, 4. Function type, 5. Electric opening support, 6. Adjustment feature, 7. Ease of assembly, 8. Packing type, 9. Color.

As a result; As can be seen from the developments in the world furniture sector, in this study, in which alternative approaches to the selection and use of furniture accessories, which have a large share in providing competitive advantage, are examined, the necessity and importance of defining the accessory selection criteria separately on a product basis by bringing together all the stakeholders in the sector has emerged.

References

Dilik, T. (1992). The hardware production sector for furniture and building elements (door-window) and its problems. MSc Thesis. Istanbul University Institute of Science and Technology, Review of the Faculty Forestry, University of Istanbul, Series-A, 42: 155–175, Istanbul, Türkiye.

Dilik, T., Erdinler, S. (2003). The structural analysis of turkish hardware production sector for furniture and development of international competition. Review of the Faculty Forestry, University of Istanbul, Türkiye, Ser. A, 53: 1, 87–111. http://dergipark.ulakbim.gov.tr/jffiu/article/view/5000080146/pdf_1313

Dilik, T., Kılıç, U., Kurtoğlu, A. (2019). Development of foreign trade and production in furniture hardware sector in Türkiye. İleri Teknoloji Bilimleri Dergisi, 8(2), 92–100. https://dergipark.org.tr/en/pub/duzceitbd/issue/51527/642148

Elişen, B., Dilik, T., Kurtoglu, A. (2018). Important criterias for the selectıon of door hardware and lockıng systems for the project. 5th International Furniture Congress: Proceedings Book Eskişehir Technical University. Faculty of Architecture and Design Publications. https://www.researchgate.net/publication/330846088

İçen, I., Dilik, T, Kurtoğlu, A. (2018). Kitchen furniture accessories and hardware specification criterions and trend project applications. 5th International Furniture Congress: Proceedings Book Eskişehir Technical University. Faculty of Architecture and Design Publications. https://www.researchgate.net/publication/336603752

Kılıç, U. (2021). The importance of hardware in furniture production and determination of the criteria in the selection of furniture hardware. MSc. Thesis, Istanbul University-Cerrahpasa Institute of Graduate Studies Department of Forest Industry Engineering. Istanbul.

Kurtoğlu, A., Dilik, T. (2020). Furniture and wood constructions lecture notes (Unpublished). Istanbul University-Cerrahpasa Faculty of Forestry, Department of Forest Industrial Engineering. Bahcekoy-Istanbul.

Kurtoğlu, A., Dilik, T. (2021). Furniture industry lecture note (Unpublished). Istanbul University-Cerrahpasa Faculty of Forestry, Department of Forest Industrial Engineering. Bahcekoy-Istanbul.

Uçar, E. (2016). Reflections of global orientations in kitchen furniture sector in turkish kitchen sector. MSc Thesis. Istanbul University Institute of Science and Technology. Istanbul, Türkiye.

Yüksel, F.Ö., Dilik, T. (2019). The effect of kitchen furniture hardware systems on user experience. The XXIX[TH] International Conference Research for Furniture Industry-Proceedings Book, Ankara, Türkiye, 19–20 Eylül 2019, s. 699–706.

URL 1. https://publications.blum.com/2020/catalogue/tr/II/ (accessed 3.17.2021).
URL 2. https://www.hafele.com.tr/INTERSHOP/web/WFS/Haefele-HTR-Site/tr_TR/-/TRY/Static-View/pdfcatalog/tr_TR/HTR-GK-2020/index.html?start-page=0.1#page_0.2 (accessed 3.17.2021).
URL 3. https://web2.hettich.com/hbh/catalog/Start.do;jsessionid= 0FA0531215467B-0B3590A9BF9CB85FB3?localeId=tr_TR&model=procat tr (accessed 3.18.2021)
URL 4. https://www.hafele.com.tr/INTERSHOP/web/WFS/Haefele-HTR-Site/tr_TR/-/TRY/Static-View/pdfcatalog/tr_TR/HTR-GK-2020/index.html?start-page=0.1#page_2.34 (accessed 3.19.2021)
URL 5. https://www.samet.com.tr/tr-TR/media/download/catalog/15524817938e88.pdf (accessed 3.19.2021)
URL 6. https://www.samet.com.tr/uploads/products/files/1585289969b2ae.pdf (accessed 3.19.2021)

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Recent developments and trends in furniture coatings

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Keywords

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furniture

Abstract

The overall growth of the furniture coatings market can be attributed to the rising worldwide population and increasing customer demand for furniture. Wood coatings are materials applied to the surface of a furniture to protect it from both natural and man-made impacts. Solvent-borne coatings continue to be used in two-thirds of all wood coatings today, followed by water-borne, UV-curable, and powder coatings. There is a significant transition toward sustainable solutions as a result of increased awareness of eco-friendly products, environmentally friendly furniture, increased quality features, lower volatile organic compound (VOC) emissions coatings, and the use of renewable green materials. Recent advancements in furniture coating technology have focused on the development of bio-based and high-performance coatings that will allow the formulation of sustainable and low-VOC coatings. This review provides a comprehensive overview of the most recent advancements and trends in furniture coatings.

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Introduction

Wood is a versatile raw material used in indoor and outdoor applications for decoration and construction. However, because wood is an organic material, it cannot naturally withstand all of the external effects to which it is subjected, especially when exposed for an extended period of time. Because of their sensitivity to light weathering and aerobic oxidation, color change in lignocellulosic composites made of wood is unavoidable (Emery and Schroeder, 1974; George et al., 2005). When exposed to UV light, the surface color change is primarily caused by chemical and physical changes in both wood and polymer (Matuana et al., 2011).

Scratches are harmful to a product's aesthetics and functionality, as well as its value. These negative properties reduce the lifetime and value of wood materials. As a result, the long-term durability and natural appearance of the materials utilized should be preserved in both indoor and outdoor conditions.

Various methods that improve the properties of the materials are now available for extending the lifetime and increasing the value of wooden materials. Coating of wood is one such method. Wood coating helps the desirable properties of wood surfaces, such as enhancing the appearance of the wooden surface and increasing durability and resistance (Bulian and Graystone, 2009). The primary function of wood coating is to maintain the wood surface in good condition. The anti-scratch coating disables issues. It also provides a more scratch-resistant surface than the original. The coating of wood appearance is mainly for surface preservation and therefore increases its utilization properties (Ramage et al., 2017). Wood coatings are utilized in hospital furniture, research laboratories, dining halls, and hotels.

The rising global population and increased customer demand for furniture can be related to the overall growth of the furniture coatings industry.

Table 1 summerized the market outlook for wood coatings between 2022 to 2032.

Table 1. Wood coatings market outlook (Fact. MR, 2022)

Expected market value (2022)	US$ 9.7 Billion
Projected forecast value (2032)	US$ 17.7 Billion
Global growth rate (2022–2032)	6.2% CAGR

This paper aims to provide a comprehensive overview of the most recent advancements and trends in furniture coatings.

Furniture wood coatings

The global furniture wood coatings market is divided into four main types: solvent-borne, water-borne, UV-cured, and powder. Solvent-borne coatings continue to be used in two-thirds of all wood coatings today, followed by water-borne, UV-curable, and powder coatings.

Solvent-borne coatings are composed of petroleum-based solvents such as ketones, toluene, xylene, and propanol. Solvents dissolve the adhesives and additives used in the coating formulation and evaporate when they react with oxygen after the coating has been applied. Solvent-borne coatings are commonly used due to the general improvement in overall finishing, flexible application, quick drying, high gloss for image distinction, low cost, and ease of application on any wood substrate. However, they have disadvantages like high flammability and VOC content.

In water-borne wood coatings, water is utilized as a solvent to disperse additives and adhesives. These coatings are made up of water and other solvents such as glycol ethers. Water-borne coatings are inexpensive and have good adhesion despite the use of additives, thinners, and hardeners. They are popular in Europe and the Americas due to their low VOC emissions.

A UV coating is a type of wood finish in which the surface is cured using ultraviolet radiation. UV coatings are non-toxic to the environment since they do not include any solvents. Unlike varnishes, they do not emit volatile organic compounds, or VOCs, when cured. When compared to other methods, the UV coating process uses much less energy.

Powder coatings have attracted attention because of their efficiency, low cost, higher performance, and environmentally friendly nature. The main difference between standard liquid coatings and dry powder coatings is that powder coatings do not require a solvent, making them more environmentally friendly. Powder wood coatings not only improve the process but also extend the lifetime of the finished products.

Conclusions

Wood coating formulations have had to deal with a few important industry developments over the last few decades, such as the transition from solvent-based to water-based, UV-Cure or powder formulations. Long-term and short-term expectations for interior wood coatings include more durable, easy-to-use/apply, lower-VOC, environmentally friendly, and more sustainable coatings. Furthermore, water-borne, UV-cured wood coatings and powder coatings will continue to be popular.

References

Bulian, F., Graystone, J. (2009). Wood coatings: theory and practice. 1st edition. Elsevier: Amsterdam.

Emery, J.A., Schroeder, H.A. (1974). Iron-catalyzed oxidation of wood carbohydrates. Wood Science and Technology, 8, 123–137. https://doi.org/10.1007/BF00351367

Fact. MR (2022). Wood coatings market. https://www.factmr.com/report/4538/wood-coatings-market (accessed 26.08.22).

George, B., Suttie, E., Merlin, A., Deglise, X. (2005). Photodegradation and photostabilisation of wood–the state of the art. Polymer Degradation and Stability, 88, 268–274. 10.1016/j.polymdegradstab.2004.10.018

Matuana, L.M., Jin, S., Stark, N.M. (2011). Ultraviolet weathering of HDPE/wood-flour composites coextruded with a clear HDPE cap layer. Polymer Degradation and Stability, 96(1), 97–106. https://doi.org/10.1016/j.polymdegradstab.2010.10.003

Ramage, M.H., Burridge, H., Busse-Wicher, M., Fereday, G., Reynolds, T., Shah, D.U., Wu, G., Yu, L., Fleming, P., Densley-Tingley, D., Allwood, J., Dupree, P., Linden, P.F., Scherman, O. (2017). The wood from the trees: The use of timber in construction. Renewable and Sustainable Energy Reviews, 68, 333–359. https://doi.org/10.1016/j.rser.2016.09.107

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Chitosan-based adhesive reinforced with pine resin

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Keywords

chitosan
pine resin
adhesive
bond strength

Abstract

Commercial adhesives have a high bond strength and are resistant to water but harm the environment and humans. Chitosan can be regarded as a versatile bio-sourced alternative. The potential of chitosan as a wood adhesive which was produced from medium molecular weight chitosan and different ratio of Pine resin, was investigated in this study. The viscosity of chitosan-based adhesive was found from 1167 CP to 2871 CP. Also, the chemical compositions of chitosan-based adhesives were analyzed via Fourier transform infrared spectroscopy. Double-lap shear tests were used to determine the bond strength of different chitosan-based formulations. The bond strength of chitosan-based adhesive was found to vary between 0,47 MPa to 0,82 MPa.

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Introduction

As a safe, easy-to-use, aesthetic structure, wood has been used as a building and engineering material since ancient times. Wooden materials are preferred mainly due to their anatomical and chemical structures and mechanical and physical properties (Ergun, 2021). However, the increasing population and requirements led to waste and small-scale wood being converted into products such as particleboard, fiberboard, plywood, and glulam. Therefore, it demands high quantity adhesive. Also, adhesives are used to bond the solid wood. Formaldehyde-based adhesives such as melamine formaldehyde (MF), phenyl formaldehyde (PF), resorcinol formaldehyde (RF), urea-formaldehyde (UF) and are primarily used in the wood material sector. These adhesives show high water resistance and bond strength. Despite all these positive features, they produce dangers for the environment and human health due to the release of free formaldehyde (Abdelmoula et al., 2021). So, researchers are attempting to develop non-toxic wood or less-toxic adhesives by diminishing the molar ratio and adding a formaldehyde scavenger during preparation (Ji and Guo, 2018). In addition, petroleum resources used in producing PF, MF, and UF resins are rapidly depleting. Therefore, developing adhesives containing no formaldehyde from non-petroleum sources is essential. In this context, bio-based adhesives were emphasized (Umemura et al., 2003). Bio-based adhesives are derived from animals, fungi, bacteria, and plants. These can be polymers that play a variety of biological functions in plants, such as energy storage (starch), cellular communication (glycosaminoglycans), or cell wall forming (cellulose). These polymers can have high molecular weights (Sorlier et al., 2001). The main structural features of polysaccharides include mainly polar functional groups and high molecular weight to exhibit adhesive properties. Polysaccharides with hydrogen-bonding functional and polar groups, namely carboxylates, ethers, and hydroxyls, demonstrate superior adhesion to high-energy bonding woods and metals. The most investigated polysaccharides for adhesives are guar gum, starch, lignin, and chitosan (Mathias et al., 2016).

Chitosan, the second most abundant polysaccharide on earth (Yıldırım et al., 2022), has many applications, including but not limited to water treatment, biomedical, wood adhesive, and insulation materials (Ozen et al., 2021). In particular, chitosan is a suitable biopolymer for use in wood adhesives. Chitosan, acquired with the deacetylation of chitin, has gotten attention due to its high potential applicability as a bioadhesive. Bioadhesives have taken place in significant advances in the biomedical sector and, more recently, in the wood construction sector. In bioadhesives, the parameters affecting the attractive features of chitosan are the degree of deacetylation and molecular weight. Many studies showed that the adhesive features change when molecular weight and the degree of deacetylation decrease. Chitin is also extracted industrially from the exoskeletons of shrimp and crabs, primarily from seafood processing waste. These characteristics enable efficient and fashionable waste management using polysaccharides in the adhesive wood field (Mati-Baouche et al., 2014).

On the other hand, pine resin is an abundant natural renewable resource in Türkiye. The main component of the resin is a resin acid mixture with a hydrogenated phenanthrene ring structure (Mao et al., 2021). Pine resins are widely used in many fields, such as agriculture, cosmetics, and health.

This study aimed to examine the usability of the adhesive produced from chitosan and different amount of pine resin for the wood industry.

Methods and materials

Materials

The medium molecular weight chitosan (molecular weights: 310000 to 375000 Da), acetic acid, and glycerol were supplied from Sigma-Aldrich (Schnelldorf, Germany). Calabrian pine (Pinus brutia) resin was collected from calabrian pine trees in Dalaman / Mugla (Türkiye).

Methods

Both calabrian pine resin and chitosan can dissolve in acetic acid conditions, so %5 stock solution of acetic acid was prepared in distilled water. Firstly, calabrian pine resin was mixed at 1200 rpm in acetic acid for 2 h. Respectively, chitosan was added and stirred at 600 rpm for 6 h. All mixing processes were carried out at room temperature. Compositions of the adhesive are given in Table 1.

Table 1. Contents of chitosan-based adhesive

Code	Chitosan (gr)	Pine Resin (gr)	Acetic Acid (5%) (ml)	Glycerol (ml)
CPA-0	10	0	125	2
CPA-1	10	1.25	125	2
CPA-2	10	3.75	125	2
CPA-3	10	6.75	125	2

*CPA – chitosan-pine resin adhesive.

The preparation method of chitosan-based adhesive is shown in Fig. 1.

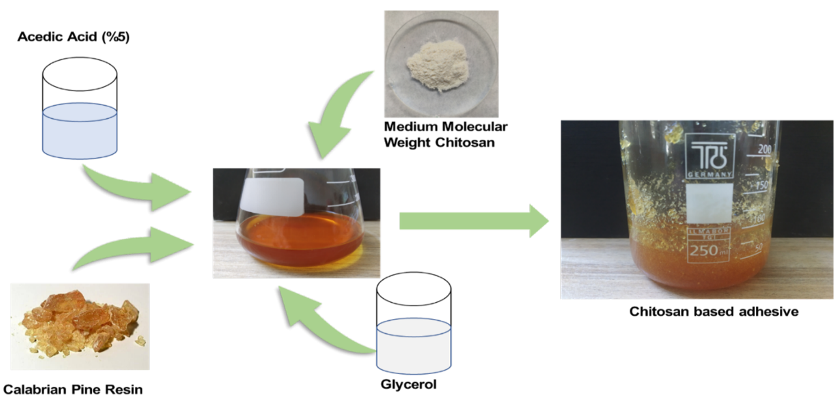

Fig. 1. Production of chitosan-based adhesive

Characterization

The viscosity of the produced glues was measured according to ISO 9665 standards with KU-2 viscometer (Brookfield, USA). Fourier transform infrared (FT-IR) analyses were carried out with a Nicolet IS FT-IR (iS10, Thermo Fisher Scientific, Massachusetts, USA) spectrometer. Each produced adhesive was measured at the spectra range of 400 cm^{-1} to 4000 cm^{-1}. Double lap samples were prepared with 5× 18 × 150 mm (thickness × width × length) dimensions, and the bonding area was 900 mm^2. 150 grams of adhesive per square meter was applied to the sample surfaces. The samples were dried at 60 °C without pressure for 6 h in the oven. The mechanical characterization of the double lap specimens was assessed on a Marestek universal test device (Mares Engineering Research Electronic Systems, İstanbul, Türkiye) according to ASTM D 3528-96 (2016) standard. After, the bond strength was calculated with the following Equation (1):

$$\sigma = \frac{F_{max}}{2A} \quad (1)$$

Where σ is the bond strength, F is the applied maximum force (N), and A is the lap area (mm^2).

Results and discussion

The viscosity of a fluid is a measurement of its resistance to gradual deformation and spreading. The viscosity properties of chitosan solutions provide essential information in adhesives. The viscosity of chitosan solutions is related to their pH and degree of deacetylation (Crini et al., 2009). In addition, temperature and concentration are other vital viscosity parameters (Mati-Baouche et al., 2014). The viscosity values of chitosan-based adhesive reinforced with pine resin are given in Fig. 2.

Depending on the pine resin concentration, the chitosan-based adhesive's viscosity ranged from 1167 CP to 2871 CP. As the amount of pine resin increased, the adhesive viscosity increased. The viscosity of chitosan-based adhesive increased due to chitosan and pine resin reacting with each other. In different studies, the viscosity values of chitosan ranged from 14 CP to 7132 CP (Jeon et al., 2002; Bajaj et al., 2011). Generally, it is desired to have high cohesion strength in adhesives, and therefore it is undesirable to use an excessive amount of filling material. Cohesion force, in a sense, determines the mechanical properties of the material. The cohesion force's magnitude

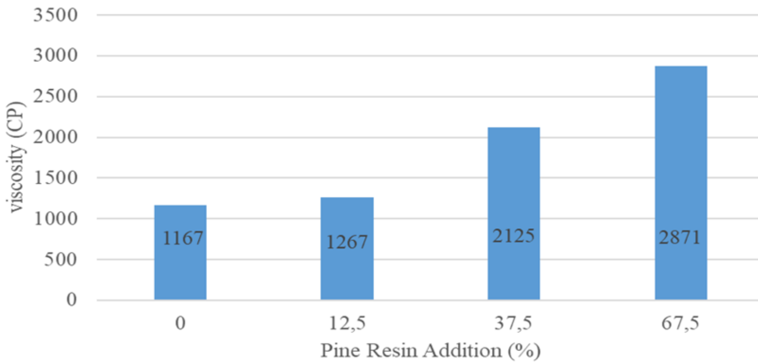

Fig. 2. The viscosity of the chitosan-based adhesive

depends on the adhesive's chemical structure, and using more than 40% filler on average affects the cohesion force in adhesion negatively (Senay, 1996).

Although the chemical structure of pine resins is very complex, all FTIR spectra of pine resins offer similar properties and, as a result, can be characterized by FTIR spectra when mixed with different polymers. FTIR spectra of chitosan, pine resin, and their mixtures are given in Fig. 3.

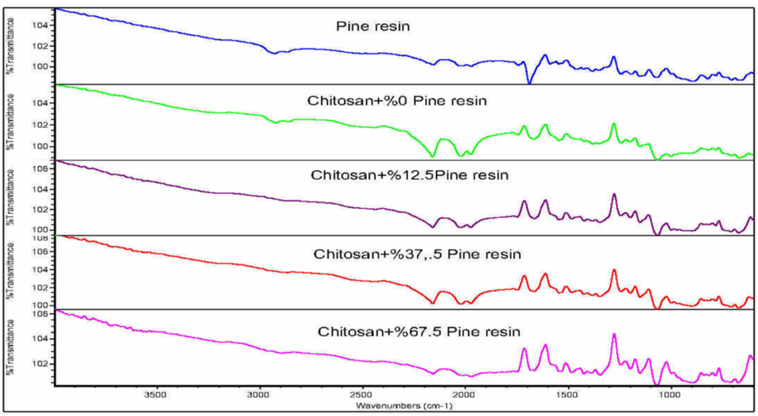

Fig. 3. FTIR results of chitosan-based adhesive

The spectra of pine resin displayed the following band: 2927 cm^{-1} could be assigned to the aliphatic C-H stretch group. This C-H stretch group is typical of highly branched and cycle-containing alkyl groups. Terpenoid compounds, the primary constituents of pine resins, contain these alkyl fragments. The presence of bands in 1689 cm^{-1} could be C–O stretching vibrations due to the carboxylic groups of resin acids. Due to C-O-C and C-O stretch vibrations, the bands are centered around 1000 cm^{-1}–1100 cm^{-1}. After the resins have been oxidized, these bands may appear in the spectra (Vahur et al., 2011). When the spectra of chitosan without pine resin were examined, 2922 cm^{-1} bands were related to C-H symmetric and asymmetric stretching, respectively. These bands are characteristics typical of polysaccharides and occur in different polysaccharide spectra, such as carrageenans (Silva et al., 2010), glucans (Wolkers et al., 2004), and xylan (Melo-Silveira et al., 2011). N-acetyl groups were affirmed at around 1665 cm^{-1} peak (C = O stretching of amide I), 1546 cm^{-1} (N-H bending of amide II), and 1380 cm^{-1} (C-N stretching of amide III), respectively. The second band (1546 cm^{-1}), characteristic of typical N-acetyl groups, was presumably overlapped by other peaks (Queiroz et al., 2014). The CH_2 bending and CH_3 symmetrical deformations were confirmed by the presence of band at around 1380 cm^{-1}. The absorption band at 1151 cm^{-1} can be attributed to the asymmetric stretching of the C-O-C bonds. The bands at 1063 cm^{-1} correspond to C-O stretching. Similar results are found in other studies (Vino et al., 2012; Song et al., 2013). As the amount of pine resin in the adhesive increased, the peak intensity observed at 2159 cm^{-1}, 2025 cm^{-1}, and 1974 cm^{-1} decreased. On the other hand, there was an increase in the C=O stress peak around 1600 cm^{-1}. In addition, the intensity of the peaks belonging to the CH_2 and CH_3 groups, found around 1380 cm^{-1}, was observed. All these changes are thought to be due to the interaction of pine resin and chitosan.

The bond strengths of the control and pine resin-reinforced chitosan-based adhesive applied to Scots pine wood are given in Fig. 4.

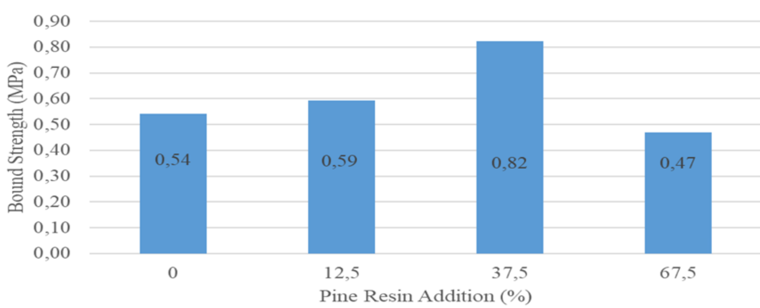

Fig. 4. The bond strength of the chitosan-based adhesive

The bond strength of chitosan-based adhesive varied between 0.47 MPa to 0.82 MPa. The highest value was obtained from CPA-2 with pine resin at %37.5 addition in the chitosan-based adhesive. CPA-3 gave the lowest bond strength value with 0.47 MPa. The bond strength of samples depended widely on the interaction between wood and adhesive. Wood has a tiny porosity. Typically, the roughness of the surfaces of adherents is of an upper order compared to this porosity. As a result of their low surface tension and adapted viscosity, chitosan solutions can penetrate deeply into these asperities. In wet conditions, positively charged chitosan (acid pH) interacts strongly with the negatively charged surface via electrostatic forces, van der Waals forces, and hydrogen bonds between D-glucosamine and the adherend or hydrated surface (Lee et al., 2013). Ji et al. (2017) produced MDF with an adhesive containing chitosan and glutaraldehyde. The bond strengths of the MDF were found to vary between 0.13 MPa and 1.22 MPa. On the other hand, the bond strengths of the adhesive produced from chitosan and lignin were between 0.9 MPa and 1.3 MPa (Ji and Guo, 2018). Patel et al. (2013) found the bond strengths of chitosan-based adhesives between 3.5 MPa and 6.1 MPa.

Conclusions

This work successfully produced novel adhesives that were fully biomass-based for wood. The viscosity of chitosan-based adhesive was found 1167 CP to 2871 CP. It was determined that the bond strength increased to 52% with the addition of pine resin compared to the control group. Also, it was found that the addition of excessive pine resin (CPA -3) had a negative effect on the bond strength. Although the chitosan-based adhesive has promising results, it is required to improve the mechanical properties using a crosslinker. Bond strengths will be evaluated in cold and hot water. In addition, the interaction between wood and adhesive will be examined with FTIR and Raman Spectrometer.

References

Abdelmoula, M., Ben Hlima, H., Michalet, F., Bourduche, G., Chavant, J.-Y., Gravier, A., Delattre, C., Grédiac, M., Mathias, J.-D., Abdelkafi, S., Michaud, P., de Baynast, H. (2021). Chitosan-Based Adhesive: Optimization of Tensile Shear Strength in Dry and Wet Conditions. Polysaccharides 2, 110–120. https://doi.org/10.3390/polysaccharides2010008

Bajaj, M., Winter, J., Gallert, C. (2011). Effect of deproteination and deacetylation conditions on viscosity of chitin and chitosan extracted from Crangon crangon shrimp waste. Biochemical Engineering Journal, 56, 51–62. https://doi.org/10.1016/j.bej.2011.05.006

Crini, G., Guibal, E., Morcellet, M., Torri, G., Badot, P.-M. (2009). Chitine et Chitosane. Préparation, propriétés et principales applications. in: Chitine et Chitosane- Du biopolymère à l'application (p. 19–54). Presses Universitaires de Franche-Comté: Besançon.

Ergun, H. (2021). Segmentation of wood cell in cross-section using deep convolutional neural networks. Journal of Intelligent & Fuzzy Systems, 41, 7447–7456. https://doi.org/10.3233/JIFS-211386

Jeon, Y.-J., Kamil, J.Y.V.A., Shahidi, F. (2002). Chitosan as an Edible Invisible Film for Quality Preservation of Herring and Atlantic Cod. Journal of Agricultural and Food Chemistry, 50, 5167–5178. https://doi.org/10.1021/jf011693l

Ji, X., Guo, M. (2018). Preparation and properties of a chitosan-lignin wood adhesive. International Journal of Adhesion and Adhesives, 82, 8–13. https://doi.org/10.1016/j.ijadhadh.2017.12.005

Ji, X., Li, B., Yuan, B., Guo, M. (2017). Preparation and characterizations of a chitosan-based medium-density fiberboard adhesive with high bonding strength and water resistance. Carbohydrate Polymers, 176, 273–280. https://doi.org/10.1016/j.carbpol.2017.08.100

Lee, D.W., Lim, C., Israelachvili, J.N., Hwang, D.S., 2013. Strong Adhesion and Cohesion of Chitosan in Aqueous Solutions. Langmuir, 29, 14222–14229. https://doi.org/10.1021/la403124u

Mao, S., Wu, C., Gao, Y., Hao, J., He, X., Tao, P., Li, J., Shang, S., Song, Z., Song, J., 2021. Pine Rosin as a Valuable Natural Resource in the Synthesis of Fungicide Candidates for Controlling Fusarium oxysporum on Cucumber. Journal of Agricultural and Food Chemistry, 69, 6475–6484. https://doi.org/10.1021/acs.jafc.1c01887

Mathias, J.-D., Grédiac, M., Michaud, P. (2016). 16- Bio-based adhesives. In: F. Pacheco-Torgal, V. Ivanov, N. Karak, H. Jonkers (Eds.), Biopolymers and Biotech Admixtures for Eco-Efficient Construction Materials (pp. 369–385). Woodhead Publishing. https://doi.org/10.1016/B978-0-08-100214-8.00016-6

Mati-Baouche, N., Elchinger, P.-H., de Baynast, H., Pierre, G., Delattre, C., Michaud, P. (2014). Chitosan as an adhesive. European Polymer Journal, 60, 198–212. https://doi.org/10.1016/j.eurpolymj.2014.09.008

Melo-Silveira, R.F., Fidelis, G.P., Costa, M.S.S.P., Telles, C.B.S., Dantas-Santos, N., Elias, S. de O., Ribeiro, V.B., Barth, A.L., Macedo, A.J., Leite, E.L., Rocha, H.A.O. (2011). In vitro antioxidant, anticoagulant and antimicrobial activity and in inhibition of cancer cell proliferation by xylan extracted from corn cobs. International Journal of Molecular Sciences, 13, 409–426. https://doi.org/10.3390/ijms13010409

Ozen, E., Yildirim, N., Dalkilic, B., Ergun, M.E. (2021). Effects of microcrystalline cellulose on some performance properties of chitosan aerogels. Maderas Ciencia y Tecnologia, 23. https://doi.org/10.4067/S0718-221X2021000100426

Patel, A.K., Michaud, P., Petit, E., de Baynast, H., Grédiac, M., Mathias, J.D. (2013). Development of a chitosan-based adhesive. Application to wood bonding. Journal of Applied Polymer Science, 127, 5014–5021. https://doi.org/10.1002/app.38097

Queiroz, F.M., Melo, K.R.T., Sabry, D.A., Sassaki, G.L., Rocha, H.A.O. (2014). Does the Use of Chitosan Contribute to Oxalate Kidney Stone Formation? Marine Drugs, 13, 141–158. https://doi.org/10.3390/md13010141

Senay, A. (1996). Technological properties of laminated wood material. PhD thesis. İstanbul University Graduate School of Natural and Applied Sciences, İstanbul, Türkiye.

Silva, F.R.F., Dore, C.M.P.G., Marques, C.T., Nascimento, M.S., Benevides, N.M.B., Rocha, H.A.O., Chavante, S.F., Leite, E.L. (2010). Anticoagulant activity, paw edema and pleurisy induced carrageenan: Action of major types of commercial carrageenans. Carbohydrate Polymers, 79, 26–33. https://doi.org/10.1016/j.carbpol.2009.07.010

Song, C., Yu, H., Zhang, M., Yang, Y., Zhang, G. (2013). Physicochemical properties and antioxidant activity of chitosan from the blowfly Chrysomya megacephala larvae. International Journal of Biological Macromolecules, 60, 347–354. https://doi.org/10.1016/j.ijbiomac.2013.05.039

Sorlier, P., Denuzière, A., Viton, C., Domard, A. (2001). Relation between the Degree of Acetylation and the Electrostatic Properties of Chitin and Chitosan. Biomacromolecules, 2, 765–772. https://doi.org/10.1021/bm015531

Şenay, A. (1996). Technological properties of laminated wood material. PhD thesis. İstanbul University Graduate School of Natural and Applied Sciences, İstanbul, Türkiye.

Umemura, K., Inoue, A., Kawai, S. (2003). Development of new natural polymer-based wood adhesives I: dry bond strength and water resistance of konjac glucomannan, chitosan, and their composites. Journal of Wood Science, 49, 221–226. https://doi.org/10.1007/s10086-002-0468-8

Vahur, S., Kriiska, A., Leito, I. (2011). Investigation of the adhesive residue on the flint insert and the adhesive lump found from the pulli early mesolithic settlement site (estonia) by micro-atr-ft-ir spectroscopy. Estonian Journal of Archaeology, 15, 3. https://doi.org/10.3176/arch.2011.1.01

Vino, A.B., Ramasamy, P., Shanmugam, V., Shanmugam, A. (2012). Extraction, characterization and in vitro antioxidative potential of chitosan and sulfated chitosan from Cuttlebone of Sepia aculeata Orbigny, 1848. Asian Pacific Journal of Tropical Biomedicine, 2, S334–S341. https://doi.org/10.1016/S2221-1691(12)60184-1

Wolkers, W.F., Oliver, A.E., Tablin, F., Crowe, J.H. (2004). A Fourier-transform infrared spectroscopy study of sugar glasses. Carbohydrate Research, 339, 1077–1085. https://doi.org/10.1016/j.carres.2004.01.016

Yildirim, N., Ozen, E., Ergun, M.E., Dalkilic, B. (2022). A study on physical, morphological and antibacterial properties of bio polymers reinforced polyvinyl acetate foams. Materials Research Ibero-american Journal of Materials, 25. https://doi.org/10.1590/1980-5373-MR-2021-0579

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A study on hinges and cabinet doors

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Keywords

cabinet
doors
hinges
deflections
aesthetic values

Abstract

The deflection of cabinet doors is a factor that effects both functional and aesthetic values of cabinet furniture. Function and aesthetics are core design issues for cabinets. This study determined deflection values of cabinet doors under varying conditions such as density moisture content, screw pull, clutch, and close and opening angle. In the study, furniture cabinet doors consisting of two different materials (medium-density board and particle board), two hinges, three hinges and four hinges were tested separately. The study is based on the BS EN 16122 standard. However, the TS EN 9215 standard was followed to reveal the deformations in the door after increasing loads and angles. As a result, it was found that the material type, angle, load is important.

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Introduction

Wood materials and wood-based materials constitute an important component of the furniture phenomenon and furniture construction design. Knowing previously the behavior of the materials involved in the formation of the furniture product against physical and mechanical effects provides technical, aesthetic and economic benefits to designers, manufacturers and users.

Kowaluk et al. (2011), studied, particleboards with different densities from specially prepared particles of black locust and willow. As an alternative light weight product. The standard mechanical parameters of panels were investigated, as well as the corner wall connections with eccentric connecting fitting element and have measured the screw withdrawal resistance and hinge bearing for investigated panels. They have found all panels, excluding low-density black locust panels, suitable for furniture production (Kowaluk et al., 2011).

Previous studies state that demountable fasteners are predominant in cabinet furniture, although they are uncommon in frame furniture (Prekrat and Spanic, 2009;

Ozkaya et al., 2010; Kucuktuvet et al., 2017; Efe and Imirzi, 2007; Yuksel et al., 2015; Smardzewski et al. 2016; Vassiliou and Barboutis, 2005). Screws and hinges are used in the doors and these fasteners are deformed by being exposed to loads like the door.

As a result of industrial applications that continue to develop, a wide variety of hinges and fittings are used to provide the rotational movement of a door. According to Smardzewski, the doors in case furniture can be opened by an angle from 110° to 360°, depending on the construction elements (Smardzewski 2015).

Using the finite element method (FEM), Zhou et al. (2012) in their study determined the maximal deflection values and strains for furniture doors, at varying configuration of hinge distribution. Based on the results, also with a consideration of the elastic properties of the employed wood-derived materials, the researchers came forward with a method of determination of the optimal number of hinges and distances between them (Zhou et al., 2012).

Furthermore researchers have studied the main assessment criterion of joint strength was the value of the breaking force or bending moment. On the other hand, stiffness have evaluated on the basis of the deflection value along the direction of load application or on the basis of the value change of the angle between the arms of the joint (Chai et al., 1993; Nicholls and Crisan, 2002).

As in Smardzewski et al. (2014) determination of furniture door stiffness manufactured from laminated particleboards are also studied. In the related study, the researchers investigat-ed the strength and stiffness of doors by observing the impact of spacings between concealed hinges as well as the diameter of screws mounting these hinges on. According to the overall results, door stiffness increased together with the increase of distances between hinges (Smardzewski et al., 2014).

This study aimed to reveal the deformations that occur in the doors after increasing loads and angles. Wit the lead of RS EN 9215 standard.

Methods and materials

Cabinet doors

Typical wooden cabinet doors of MDF and PB with dimensions of 1800 mm (height) × 450 mm. (width) × 18 mm (thickness) were chosen randomly from the company's production line to investigate. In the study, total of 6 cabinet doors manufactured with two different materials were tested. The cabinet doors were labelled as from 2 hinges MDF1, PB1; 3 hinges MDF1, PB1 and 4 hinges MDF1, PB1 (Fig. 1). Accordingly, moisture and density determinations were conducted with 15 small samples taken from each door. Moisture determination was performed according to EN 322(1993), while density determination was performed according to EN 323(1993) while density determination was per-formed according to EN 323(1993) standard. In this direction, the moisture content and density values are shown in Table 1.

Table 1. The moisture content and density values

Material		Door with 2 hinges	Door with 3 hinges	Door with 4 hinges
MDF	moisture cont.	%7.86	%7.26	%7.40
	density	0.718 g/cm^3	0.717 g/cm^3	0.716 g/cm^3
PB	moisture cont.	%8.47	%9.54	%8.12
	density	0.63 g/cm^3	0.64 g/cm^3	0.60 g/cm^3

All screws were screwed in with the assistance of commercial screwdrivers equipped in a clutch. The screwdriver was set to achieve a drive-in moment value of 2.4 Nm.

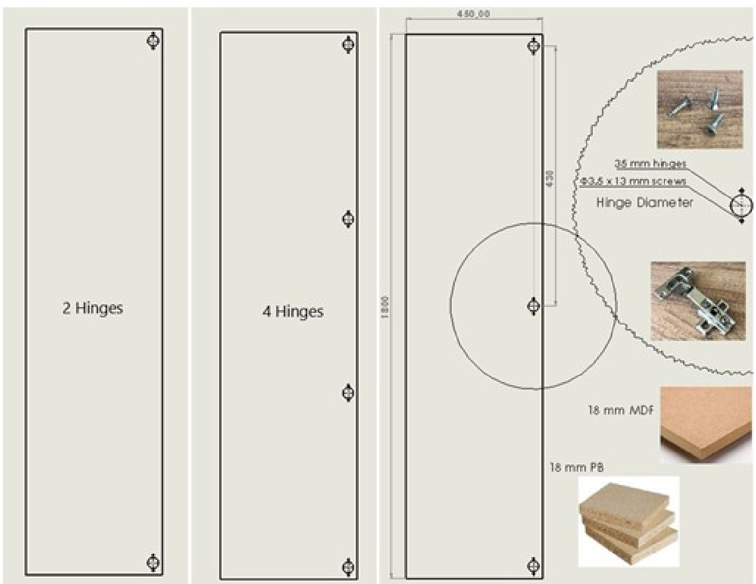

Fig. 1. Illustration of tested cabinets and materials

Test method for doors

Each of the hinges were marked around by a pen in order to investigate their displacement and rotation. Loading of the door with the specified mass is as shown in Fig. 2. The load is suspended 100 mm from the edge furthest from the hinge. The door is opened and closed ten full turns (back and forth) from position of 45° from fully closed position to 10° position from fully open position to maximum 135° position with an auxiliary element. Opening and closing was performed by Durability and Stability Furniture Testing Equipment machine. The study is based on the BS EN 16122(2012) standard. However, the TS EN 9215(2005) stand-ard was also followed in order to reveal the deformations that occur in the door after increasing loads. For this reason, forces of 375N and 450N were loaded in addition to 300N loads and opening from fully closed to 10° angle, from fully closed to 135° angle and additional 10° from 45° from fully closed position are performed in accordance to TS EN 9215.

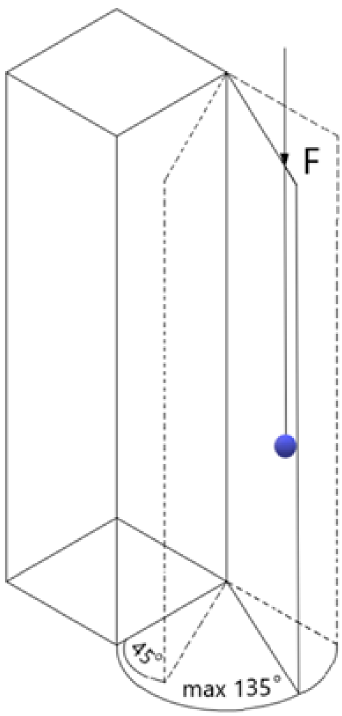

Fig. 2. Loading position of the doors

The cycle was repeated 10 times for each sample. The main criteria of the quality assessment of the examined hardware comprised deformations caused by the applied load force and deflection values of all samples.

Results and discussion

In the study, cabinets with two, three and four hinges were tested according to the standarts. As the result of the tests deformations were observed at the hinges, doors and the fixation points of the door and the body part of the cabinets. Opening and closing angles, applied loads and repetition results were taken into consideration.

Damage symptoms door with 2 hinges

Two-hinged identical dimensioned MDF and PB cabinet door tests were performed initially. As the result of the tests, top hinge of MDF doors ended up with severe

Fig. 3. Two-hinged MDF door after test

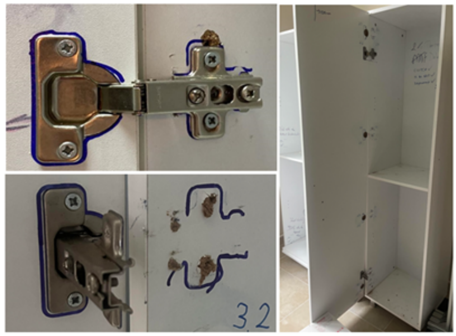

Fig. 4. Two-hinged PB door after test

rotation and bending was observed on the bottom hinges due to loads.The doors were unable to close properly as the result of hinge deformation. (Fig. 3). Meanwhile, malfunctioning of bottom hinge on PB doors occurred after 450N load. Top hinges performed higher rotation with respect to MDF doors and malfunctioning was determined due to bottom hinge displacement (Fig. 4).

Damage symptoms door with 3 hinges

The tests for three-hinged doors with identical dimensions were performed for different materials such as MDF and PB. In the test results of MDF doors under 375N load mid- hinge was dislocated and was out of the system as illustrated in Fig. 5.

Fig. 5. Three-hinged MDF door after test

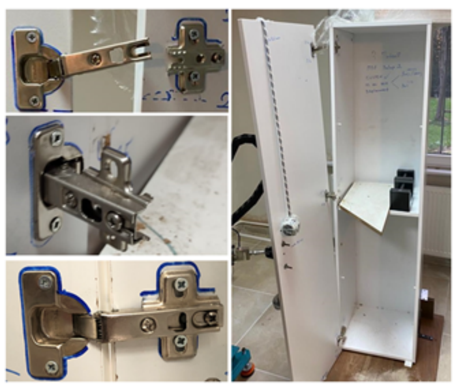

Fig. 6. Three-hinged PB door after test

Hence, the tests were proceeded as the opening-closing functions of the doors were still operating. At the end of the test, deformation due to rotation was observed on the top hinge where it was only the loosening of the screws for the bottom hinges. On the other hand, during the tests of the PB doors, dislocation of screws were observed on the mid-hinges under the load of 375N and under 450N load and 10° angle dislocation of the hinge itself was observed which caused misfunctioning of the door. The test was termintated at this point.

Damage symptoms door with 4 hinges

Four-hinged MDF cabinet tests were performed and the results were successful as shown in Fig. 7. Hence, severe rotation of the bottom hinges and displacement of other three hinges were observed. The tests proceeded as the opening-closing functions of the doors were still operating. Meanwhile, PB doors, as shown in Figure 8, the dislocation of the second hinge from the top occurred under 375 N load due to repetitions. The tests were proceeded as the doors were still functioning. At the final stage of the tests rotation of all hinges, displacement of all hinges, loosening of screws and displacement of door were observed.

In the study, increase in deflection values under different loads were determined. In another study, Smardzewski and Majewski determined the deflection values of the doors under a load of 300 N and determined that the door not only rotated during loading, but also displaced downwards which supports the results of this study.

Fig. 7. Four-hinged MDF door after test

Fig. 8. Four-hinged PB door after test

According to the experiment results, MDF 1 and MDF 2 displayed higher performance values with comparison to PB 1 and PB 2. Similarly, in his study Sert determined higher performance values for MDF on different hinge configurations for MDF and particleboard (Sert 2018).

Conclusions

As a result of these tests, the doors made of MDF material are more durable than those made of PB material. By investigating the density and moisture conditions of all door materials, it was observed that there were no outliers, the torque of all screws was fixed and possible differences were eliminated.

It has also been clearly seen that the position of the hinges on the door, which is generally separated from the system, is collected in the middle hinge, and screw loosening was encountered during the tests.

Material type, angle and load variables were determined to be effective on deflection values utilizing variance analysis. At the same time, the interaction between material type and load was found to be significant.

In the study performing three different loads, four different angles, and two materials, the factor determined to be affecting the displacement amount in the doors is angles. The results also include that it caused visible deformations in the hinges during the tests conducted at different angles in the experiments

References

Cai, L., Wang, F. (1993). Influence of the stiffness of the corner joint on case furniture deflection. Holz als Roh- und Werkstoff, 51, 406–408. 10.1007/BF02628238

Efe, H., Imirzi, H.Ö. (2007). Mechanical behaviour properties of various fasteners used in furniture production. J Polytech, 10, 93–103.

Kowaluk, G., Fuczek, D., Beer, P., Grześkiewicz, M. (2011). Influence of the raw materials and production parameters on chosen standard properties for furniture panels of bio-composites from fibrous chips. BioResources, 6(3), 3004–3018. 10.15376/BIORES.6.3.3004-3018

Kucuktuvek, M., Kasal, A., Kusgun, T., Erdil, Y.Z. (2017). Utilizing poppy husk-based particleboards as an alternative material in case furniture construction. BioResources, 12, 839–852. 10.15376/biores.12.1.839-852

Nicholls, T., Crisan, R. (2002). Study of the stress-strain state in corner joints and box type furniture using finite element analysis (FEA). European Journal of Wood and Wood Products, 60(1), 66–71. 10.1007/s00107-001-0262-0

Ozkaya, K., Burdurlu, E., Ilce, A.C., Ciritcioglu, H.H. (2010). Diagonal tensile strength of an oriented strand-board (OSB) frame with dovetail corner joint. BioResources, 5:2690–701. 10.15376/biores.5.4.2690-2701

Prekrat, S., Spanic, N. (2009). Scientific methods for determination of wooden corner joint designs. Drvna industrija, 60, 245–251. https://hrcak.srce.hr/clanak/69119

Smardzewski, J. (2015). Furniture Design. Springer International Publishing Switzerland. 10.1007/978-3-319-19533-9

Smardzewski, J., Lewandowski, W., Imirzi, H.O. (2014). Elasticity modulus of cabinet furniture joints. Materials & Design, 60, 260–266. 10.1016/j.matdes.2014.03.066

Smardzewski, J., Rzepa, B., Kilic, K.H. (2016). Mechanical properties of externally invisible furniture joints made of wood-based composites. BioResources, 11, 1224–1239. 10.15376/biores.11.1.1224-1239

Vassiliou, V., Barboutis, I. (2005). Screw withdrawal capacity used in the eccentric joints of cabinet furniture connectors in particleboard and MDF. Journal of Wood Science, 51:572–6. 10.1007/s10086-005-0708-9

Zhou, J., Hu, C. H., Hu, S., Yun, H., Jiang, G. (2012). Optimization of hinge configuration of furniture doors using finite elements analysis. BioResources, 7(4), 5809–5816. 10.15376/biores.7.4.5809-5816

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Nanotechnology in the furniture industry: applications and future perspectives

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Keywords

nanoscience
nanotechnology
smart furniture
furniture industry

Abstract

Nanotechnology has the potential to significantly improve every industry, produce innovative materials and products, and revolutionize all areas of life. Many industries have benefited from the advantages of nanotechnology advances during the last 20 years. On the other hand, the furniture industry has recently embraced these works and begun to focus its research on this area. Nanotechnology makes it possible to make furniture lighter, more durable, waterproof and stainproof, antibacterial, antiviral, and less flammable. In the near future, nanotechnology could be used to develop smart furniture that can warm up in cold weather, become opaque against solar reflections, change color, measure basic body functions, and self-healing repair scratches and small damage. This review presents a comprehensive overview of nanotechnology applications in the furniture industry, as well as recent trends, advancements, and future perspectives.

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Introduction

Furniture is products that differ in terms of functional, aesthetic, design, and design and are generally obtained from wood materials and derivatives to meet people's social and cultural needs, such as working, resting, eating, and meeting safely and comfortably. Furniture is functional since it meets human needs and reflects the person who uses it with a design line.

The global furniture industry is growing in terms of production, imports, and exports. Furniture's future is now on a dynamic, aesthetic course, with personalized designs that prioritize people's wants, designs suitable for structures, ergonomics, functionality, and unique lines.

Furniture damage is triggered by biological factors such as insects and bacteria, environmental factors such as dust, sunshine, and humidity, and man-made factors such as soiling, fire, and breaking forces.

Fig. 1 shows some of the factors that cause furniture damage.

Fig. 1. Some of the factors that lead to furniture damage (Mahran, 2019)

Advancements in nanotechnology have benefited a wide range of industries during the last 20 years. In contrast, the furniture industry has only recently entered these works and begun to focus its research on this area. Using nanotechnology, materials can be improved and made stronger, lighter, and more durable.

This paper provides a brief overview of furniture industry applications of nanotechnology.

Nanoscience and Nanotechnology

The prefix "nano" refers to a Greek prefix that means dwarf or very small and represents one millionth of a meter (10^{-9} m). Nanoscience is the study of structures and molecules with nanometer sizes ranging from 1 to 100 nm, whereas nanotechnology is the implementation of these structures and molecules in practical applications such as devices (Mansoor and Fauzi Soelaiman, 2005).

Nanotechnology in The Furniture Industry

In the furniture and wood-based products industry, nanotechnology has great promise (Jasmani et al., 2020). Nanotechnology could lead to stronger, multifunctional, yet lighter wood-based products (Bajpai, 2016). It is possible to use nanotechnology to produce furniture that is lighter, more durable, waterproof, stainproof, antibacterial, and antiviral, as well as less flammable. Nanotechnology can be used to create wood products that are more environmentally friendly and resistant to parasites and fungi. The improvement of wood's durability, resistance to water's tendency to swell it, and resistance to stress and strain are all made possible by nanotechnologies. Nanotechnology could soon be used to produce smart furniture that can measure fundamental bodily functions, warm up in cold weather, become opaque against solar reflections, change color, and self-heal scratches and minor damage.

Conclusions

Nanotechnology is one of the most promising technologies of the 21st century. Both locally and globally, nanotechnology can significantly improve and change the furniture industry's landscape. Nanotechnology could be used in the near future to build smart furniture that can warm up in cold weather, become opaque against sun reflections, change color, measure basic physiological functions, and self-heal scratches and minor damage.

References

Bajpai, P. (2016). Pulp and paper industry: nanotechnology in forest industry. Elsevier: 1st ed. Amsterdam, The Netherlands.

Jasmani, L., Rusli, R., Khadiran, T., Jalil, R., Adnan, S. (2020). Application of nanotechnology in wood-based products industry: a review. 15: 207. https://doi.org/10.1186/s11671-020-03438-2

Mahran, S. (2019). Nanotechnology effects on furniture product. Journal of Architecture, Arts and Humanistic Science, 4(14), 268–289. https://doi.org/10.21608/mjaf.2019.25781

Mansoori, G., Fauzi Soelaiman, T. (2005). Nanotechnology — An introduction for the standards community. Journal of ASTM International, 2, 1–22. https://doi.org/10.1520/JAI13110

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Effect of nano material ratio on some physical properties of wood plastic nanocomposites

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Keywords

wood
nano
plastic
composite

Abstract

Effect of multi walled carbon nanotubes (CNT) content on some physical properties of wood plastic nanocomposites were investigated. To meet this objective, pine wood flour, polypropylene with coupling agent (maleic anhydride grafted polypropylene), and multi-walled carbon nanotube (0, 2, 4 or 6 wt%) were compounded in a high speed mixer. The mass ratio of the pine wood flour to polypropylene was 50/50 (w/w) in all the composite formulations. Test samples were manufactured using hot pres from the mixture. The thickness swelling and water absorptionbproperties of the wood plastic nanocomposites reinforced with CNT were determined.

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Introduction

Materials formed by combining two or more materials of the same or different groups at the macro level in order to combine the best properties of two or more materials of the same or different groups or to create a new property are called "Composite materials". In other words, it can also be called materials consisting of different types of materials or phases brought together in order to obtain superior properties by correcting each other's weaknesses (Mengeloğlu and Karakus, 2008). Wood-plastic composites (WPC) are composites of lignocellulosic materials and plastics is a general name given to composites formed as a result of mixing. Many wood species, primarily pine, maple and oak, are used in wood plastic composites. Today, the choice of wood species is determined according to availability rather than its properties. In addition, wood-based industrial wastes and agricultural wastes can be utilized in wood plastic composite production (Clemons, 2002; Kylosov, 2007; Mengeloğlu ve Kabakçı, 2008).

Plastics are organic polymeric substances that are generally solid at normal temperature and can be shaped or moulded by mechanical methods using pressure and heat (Hüner, 2008). Wood plastic composites are divided into two main groups depending on the type of plastic used. These are defined as thermoset and thermoplastic based wood composites. In the production of thermoset based wood composites, various adhesives such as urea formaldehyde, phenol formaldehyde, melamine formaldehyde, polyvinyl acetate are generally used as binding materials. is being used. In the production of thermoplastic-based wood composites, wood materials and polyethylene, Plastics such as polypropylene, polyvinyl chloride are used (Birinci, 2011).

Various additives are used to improve the physical, mechanical and thermal properties of wood plastic composites. For this purpose, glass fibers, inorganic fibers such as carbon and borane and synthetic polymers such as kevlar and aramid fibers are used as reinforcements. Despite the many advantages of wood plastic composites, some shortcomings such as relatively low modulus value, low impact resistance and creep performance have led researchers to the necessity of using compatibilizers or nanoparticles acting as various interfacial adhesives to improve the performance of wood plastic composites. Especially today, nanotechnology studies are progressing at a great pace. It seems possible to obtain successful results in wood plastic composites with materials with high specific properties produced with nanotechnology. In this way, it is expected that wood plastic nanocomposites will become high performance and high value-added products for end-use with their advantages such as high modulus value, high impact resistance and thermal stability. The main objective of this study was to evaluate the effect of CNT nano filler content on some physical properties of wood plastic nanocomposites.

Methods and materials

Materials

Yellow pine (*Pinus sylvestris*) wood flour was used as a lignocellulosic filler. The flour was purchased from a wood-plastic composite deck manufacturer (Semadeck, Tekirdag, Turkey). The wood flour (sapwood part) passing through a 40-mesh screen was retained on an 80-mesh screen. Polypropylene (PP) with a density of 0.9 g/cm^3 was purchased from Borealis Incorp in Austria. It has a melting point of 170°C and a melt flow index of 2.5 g/10 min at 230°C. To eliminate the incompatibility between the polypropylene and the pine wood flour and to increase the bonding, maleic anhydride polypropylene (MAPP) (Optim-425; melt flow index about 120 g/10 min at 190°C and a density 0.91 g/cm^3 Pluss Polymers Pvt. Ltd., Gurugram, India) was used. As the reinforcing filler, carbon nanotubes (CNT) (Grafen Company, Ankara, Turkey) was used. Polypropylene, pine wood flour (WF), CNT, and the compatibilizer maleic acid grafted polypropylene (MAPP) were used as purchased from the manufacturer. The readymade wood flour was oven-dried at 103°C ±2°C for 24 h. Drying the wood flour was important because moisture in lignocellulosic fillers causes bubbles to form during the extrusion and injection molding processes, leading to performance loss.

Methods

The production of WPNs was carried out in two stages: pellet production and nanocomposite production. In the first stage, small granules (pellets) were produced, while in the second stage the samples were hot pressed into boards. Prior to the production, the wood flour was dried until the moisture was reduced to below 1%. The dried wood flour was melted in the extruder by premixing it with the polypropylene (PP), CNT, and MAPP according to the production prescription (Table 1) and then pushed into the die with the screw in the double screw extruder (temperature of 185°C to 200°C). The molten material that exited through the die in the extruder end was cooled with cold water and left to dry. Composite samples in the shape of fine rods dried at 80°C for 3 h were made into pellets via a plastic crusher.

Table 1. Composition of the evaluated formulations

ID	WF (wt%)	CNT (PhC)*	PP (wt%)	MAPP (wt%)
A	50	0	50	3
B	50	2	50	3
C	50	4	50	3
D	50	6	50	3

A computer-controlled press was used to apply hot pressing to the mats. The maximum press pressure was 45 N/cm^2, the press temperature was 210°C, and the total press cycle was 500 s. Following the hot pressing cycle, the ready panel was moved from hot press to climate controlled room for cooling. Before characterization, the samples were conditioned in a climate room at 23 ±2°C temperature and 65 ±2% relative humidity.

The tests were performed in accordance with ISO 62 for thickness swelling and water absorption. The samples utilized for this purpose were 5 × 5 mm in size. The samples that were conditioned in a climate room at 23 ±2°C temperature and 50% ±5 relative humidity were measured after leaving in water for 1 and 28 days.

Results and discussion

Table 2 represents some of the physical characteristics of CNT-reinforced wood plastic nanocomposites.

Table 2. Some physical properties of WPNs reinforced with CNT (%)

WPN code	Physical properties			
	thickness swelling		water absorption	
	1-day	28-days	1-day	28-days
A	0.78	2.89	0.54	1.48
B	0.75	2.78	0.51	1.42
C	0.66	2.71	0.41	1.32
D	0.61	2.67	0.35	1.30

Due to CNT's hydrophobic nature, incorporation of CNT nanoparticles into the composite structure led to low TS and WA values, as expected. The physical characteristics of the WPNs significantly improved with CNT nanoparticles loading. The control samples without the CNT had the highest TS and WS with value of 0.78% and 0.54% respectively, while the lowest TS and WS with value of 0.61% and 0.35% was found for the samples containing 5 wt-% the CNT with MAPP respectively. The merging of nanoparticles into the composite structure using the dry blending method resulted in poor dispersion of CNT nanoparticles. This situation caused a significant increase in the TS and WS of WPNs produced using the dry blending method.

The addition of the MAPP greatly increased the dimensional stability of the nanocomposites reinforced with CNT. As a consequence of the MAPP's increased coherent interfacial structure between the wood flour, PP matrix, and CNT nanoparticles, there are fewer microvoids and fiber-polypropylene-CNT debondings in the interphase area. Similar results were also found by several researchers (Wang et al., 2001; Kord et al., 2011; Kord, 2012). They found that modification of the nanocomposites with MAPP increased the dimensional stability.

Conclusions

This study was to investigate effect of CNT loading on some physical properties of wood plastic nanocomposites The result showed that the water absorption and thickness swelling properties of the nanocomposites improved with increasing CNT loading. As can be directly seen, water absorption and thickness swelling of wood-plastic nanocomposites reinforced with MWCNTs increased with increasing immersion time.

References

Birinci, E. 2011. Production of new wood-plastic composites from acetylated scots pine (*Pinus sylvestris* L.) wood flour, MSc. Thesis, Institute for Institute of Natural and Applied Sciences, Department of Forest Industrial Engineering, Kahramanmaraş Sütçü İmam University.

Clemons, C. (2002). Wood–plastic composites in the United States: The interfacing of two industries. Forest Products Journal, 52, 6, 10–18. https://www.fs.usda.gov/research/treesearch/8778

Mengeloğlu, F., ve Kabakçı, A. (2008). Determination of thermal properties and morphology of eucalyptus wood residue filled high density polyethylene composites. International Journal of Molecular Sciences, 9(2), 107–119. 10.3390/ijms9020107

Mengeloğlu, F., Karakus, K. (2008). Thermal degradation, mechanical properties and morphology of wheat straw flour filled recycled thermoplastic. Sensors, 8, 497–516. https://doi.org/10.3390/s8010500

Kord, B., 2012: Effects of compatibilizer and nanolayered silicate on physical and mechanical properties of PP/bagasse composites. Turk. J. Agric. For. 36(4): 510–517. https://doi:10.3906/tar-1105-4.

Kord, B.; Hemmasi, A.H.; Ghasemi, I., 2011: Properties of PP/wood flour/organomodified montmorillonite nanocomposites. Wood Sci. Technol. 45: 111–119. https://doi.org/10.1007/s00226-010-0309-7.

Kylosov, A.A. (2007). Wood plastic composites. John Wiley&Sons, Inc. NJ, USA, 698.

Wang, K.H., Choi, M.H., Koo, C.M., Choi, Y.S., Chung, I.J. (2001). Synthesis and characterization of maleated polyethylene/clay nanocomposites. Polymer, 42(24), 9819–9826. https://doi.org/10.1016/S0032-3861(01)00509-2.

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The effect of screw and adhesive type on screw direct withdrawal resistance in plywood, particleboard and MDF

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Keywords

allen screw
particleboard screw
adhesive
plywood
particleboard
MDF

Abstract

Screws are the leading fasteners used in furniture production today. Particleboard screws and allen screws are the most common types of screws. The resistance of the furniture connection point is one of the most important factors that determine the strength of the products produced. The use of adhesive during screwing is one of the methods applied in order to increase the resistance of the connection point. In this study, the effect of allen screw and particleboard screw on the screw direct withdrawal resistance (SDWR) of plywood, particleboard and MDF using PVAc and PU adhesive was investigated. Allen screws with dimensions of 6.3x50 mm and particleboard screws with dimensions of 6.0x50 mm were used. 1 drop of PVAc or PU adhesive was applied with a 5 ml injector into the pilot holes drilled on the samples. SDWR tests were carried out on the Zwick Roell Z050 universal testing machine according to TS EN 320 and TS EN 13446 standards. According to the results of the study, the highest SDWR was found in plywood using PU and particleboard screws. The lowest SDWR was determined in particleboard, which did not use any adhesive and allen screw was used.

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Introduction

Screws are used in all areas such as furniture, construction, etc. where wood and wood-based materials are used. Screws are the leading fasteners used in furniture production today. Particleboard screws and allen screws are the most common types of screws. Allen screws are undoubtedly one of the most used fasteners in the production of demounted furniture today (Efe and İmirzi, 2007).

The resistance of the furniture connection point is one of the most important factors that determine the strength of the products produced. Determining the screw direct withdrawal resistance between various types of screws used in joining building and furniture elements and wood-based materials is important in terms of the strength of the entire systems to be created with these materials. The use of adhesive during screwing is one of the methods applied in order to increase the resistance of the connection point (Efe et al., 2009; Jivkov et al., 2017; Krzyżaniak et al., 2021).

In this study, the effect of allen screw and particleboard screw on the screw direct withdrawal resistance (SDWR) of plywood, particleboard (PB) and MDF using polyvinyl acetate (PVAc) and polyurethane (PU) adhesives were investigated.

Methods and materials

Materials

The materials used in this study were 18 mm thick marine plywood, MDF, and PB. The plywood was produced by a local company using beech veneers and phenol formaldehyde adhesive. MDF and PB boards (uncoated) are produced in a factory in Kastamonu, Turkey.

Within the scope of the study, two types of screws, zinc-coated allen and particleboard screws, and two types of adhesives, PVAc and PU (Apel Company), were used. Allen screws were 6.3 × 50 mm, and particleboard screws were 6.0 × 50 mm.

Methods

The air-dry densities of the boards were determined (TS EN 323). The boards are cut to 50 × 50 mm^2 dimensions (TS EN 13446). Pilot holes with a diameter of 80% of the screw diameter were drilled on the edges of the boards (Fig. 1). Pilot holes were drilled with a dremel drill to a depth of 80% of the length at which the screws will penetrate the sample (34 mm).

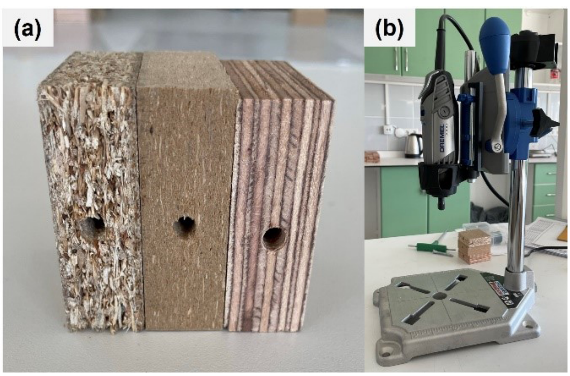

Fig. 1. (a) Plywood, MDF and PB boards; (b) Dremel drill

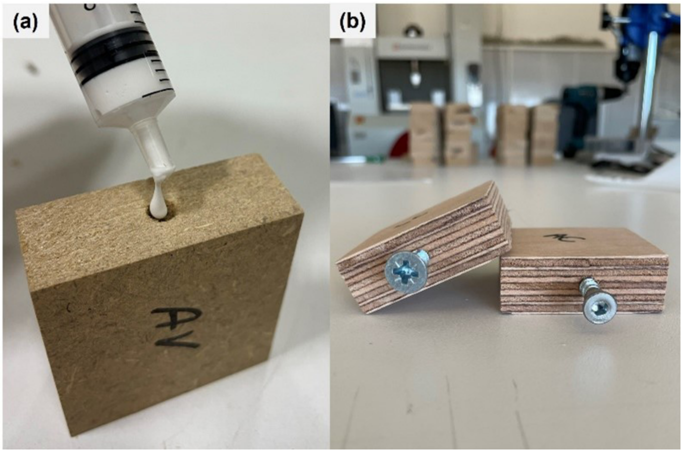

Fig. 2. a) Adhesive applying; b) Screwed boards

Within the scope of the study, 12 groups were formed based on screw type, adhesive type, and board type.15 samples were prepared for each group of boards. With a 5 ml injector, 2 drops of PVAc or PU adhesive were injected into the pilot holes drilled in the samples (Fig. 2a). Screwing processes were performed on samples with and without adhesive applied inside the pilot holes (Fig. 2b). For two weeks, plywood, MDF, and PB panels were kept at 20°C 2°C and 65% relative humidity (TS EN 320). SDWR tests were carried out on the Zwick Roell Z050 universal testing machine (TS EN 320 and TS EN 13446).

Results and discussion

According to the results of the tests carried out, the air-dry densities of the boards are shown in Table 1. According to the results in Table 1, the highest density was obtained in plywood, followed by MDF and PB, respectively. It has been understood that the results obtained are compatible with the literature.

Table 1. Air dry density test results

Board Type	Air Dry Densities (g/cm^3)
Plywood (Beech/PF)	0.75 ±0.09
MDF	0.66 ±0.04
Particleboard	0.59 ±0.06

Table 2 shows the SDWR test results applied to plywood, MDF, and PBs. When Table 2 is examined, it is clear that plywood has the highest SDWR value based on the board type.Plywood was followed by MDF and PB, respectively.

On the other hand, it is widely assumed in Table 2 that the mean SDWR of MDF is greater than that of PB.This is thought to be due to the fact that MDF has a more uniform vertical density profile than PB, its internal bond resistance, fiber/chip properties, and its adhesive type and ratio (Mcnatt, 1986; Wang et al., 2007).

Table 2. Screw direct withdrawal resistance test results

Screw Type	Adhesive type	SDWR (N)		
		plywood	MDF	particleboard
Allen screw	no adhesive	5,850.82 ±266.13	845.98 ±99.00	565.21 ±87.82
	PVAc	6,118.56 ±272.21	933.36 ±108.34	643.47 ±73.39
	PU	6,763.91 ±200.10	1,103.53 ±118.01	694.05 ±99.43
Particle-board screw	no adhesive	6,127.70 ±260.28	1,058.25 ±159.97	757.72 ±104.94
	PVAc	6,620.45 ±260.33	1,255.27 ±143.53	809.10 ±93.81
	PU	6,935.83 ±217.90	1,410.79 ±198.83	876.49 ±117.93

It has been determined that the SDWR values of all board types using particleboard screws are generally higher than those using allen screw. This study also looked at what happened to SDWR when adhesive was put in the pilot holes. It has been determined that applying the adhesive into the pilot holes generally increases the SDWR value between 6–30%. As a result of the SDWR tests carried out, the highest value was obtained in the samples applied with PU adhesive.

When the results in Table 2 were examined, it was understood that there was no linear relationship between the use of adhesive and the type of screw. PVAc adhesive was found to improve the SDWR value by an average of 6% in plywoods, 14% in MDFs, and 10% in PBs.On the other hand, it was determined that PU adhesive increased the SDWR value by an average of 14% in plywood, 30% in MDF, and 19% in PB. The use of both types of adhesive was understood to increase the SDWR value in MDF boards more than other board types.It is thought that the main reason for this is that MDF boards are more homogeneous than other boards.

Another research topic is how the use of allen screws and particleboard screws affects the SDWR value.In this study, it was found that the SDWR test results of the samples with particleboard screws were about 21% higher than the SDWR test results of the samples with allen screws.

Conclusions

The use of wood-based materials such as plywood, MDF, and PB has increased in recent years. Taking into account the mechanical properties of these materials, this study looked at how the SDWR performed depending on the type of screw, the type of adhesive used in the pilot holes, and the type of wood-based board.

According to the results of the study, it was understood that the applying of adhesive to the drilled pilot holes increased the SDWR. It has been determined that the SDWR values of the PU applied boards are higher than the PVAc applied boards.

References

Efe, H., İmirzi, H.Ö. (2007). Mechanical behaviour properties of various fasteners used in furniture production. Journal of Polytechnic, 10(1), 93–103.

Efe, H., Kasal, A., Dizel, T., Arslan, A.R., Erdem, H.E. (2009). Masif ve lamine ağaç malzemelerin (LAM) alyan vida tutma mukavemeti. Kastamonu University Journal of Forestry Faculty, 9(2), 95–105. https://app.trdizin.gov.tr//makale/T1RjeE9ERXg

Jivkov, V., Kyuchukov, B., Simeonova, R., Marinova, A. (2017). Withdrawal capacity of screws and confirmat into different wood-based panels. In: Proceedings of the XXVIIIth International Conference Research for Furniture Industry, Poznan, Poland (pp. 21–22).

Krzyżaniak, Ł., Kuşkun, T., Kasal, A., Smardzewski, J. (2021). Analysis of the internal mounting forces and strength of newly designed fastener to joints wood and wood-based panels. Materials, 14(23), 7119. https://doi.org/10.3390/ma14237119

Mcnatt, J.D. (1986). Screw-holding, internal bond, and related properties of composite board products for furniture and cabinet manufacture: A survey of literature. In: FPS proceedings 47357. Greensboro, North Carolina, USA. 47357: 30–35.

Wang, X.A., Salenikovich, A., Mohammad, M. (2007). Localized density effects on fastener holding capacities in wood-based panels. Forest Products Journal, 57(1/2), 103–109. https://www.researchgate.net/publication/237639918_Localized_density_effects_on_fastener_holding_capacities_in_wood-based_panels

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Structural analysis of a chair side frame connected with semi-rigid joints by slope-deflection method

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Key words

furniture
chair side frame
slope-deflection method
structural analyses
semi-rigid joints

Abstract

Frame furniture structures are formed by beams and connections behave as semi-rigid joints. Fur-niture engineering process that including the structural analyses should be developed to produce suitable furniture designs in the intersection of art and science. Due to excessive lateral displace-ments, connection points become highly critical to face with a sudden failure. At that point, slope deflection method can be used as a valuable method for calculating the critical moment values at the member ends that will occur as a result of relatively large lateral displacements, especially in the case of lateral loads, for the flexible furniture with semi-rigid connections. Although the slope deflection method is a fundamental, classical method for analysis, specifically, slope-deflection method was never been utilized for analysis of wooden furniture frame structures. In this study, the slope-deflection method was utilized to a representative side frame of chair, which also in-cludes semi-rigid connections in the problem, to facilitate the static analysis. By reducing and in-creasing the stiffness/rigidity of joints, the displacements were evaluated and it was shown that this method could also be used efficiently in structural analysis of furniture frames.

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Introduction

Although furniture is a structural system, it has not been the subject of mathe-matical theories until recently, and science of furniture engineering has still not been systematically applied in the Furniture Industry (Kasal, 2004). However, it is becoming increas-ingly important because of the various reasons such as; consumer demands for more reliable furniture, government pressures for warranties of furniture, increasing needs for material economics, etc. According to Eckelman furniture is the forgotten child of engineering sciences (Eckelman, 2003). Furniture engineering should be developed to produce suita-ble furniture designs in the intersection of art and science. So, this forgotten child should be raised and related studies should be carried out to contribute to furniture engineering field.

In the engineering design of the furniture, firstly, the forces acting on the ends of members have been analyzed by means of various structural analysis methods, then, stresses in these members could be calculated and by comparing with the acceptable design stresses for the materials used, thus, it can be seen whether or not each of the members has been safely designed. This process provides a methodological approach for designing a piece of furniture to meet any specified service condition.

In general for furniture products, three essential construction methods were used. Furniture was built by the case or frame method or by a combination of the two, the complex method. The case method means that the elements of furniture were plates. In the frame method, the elements of furniture were beams instead of panels (Eckelman, 2003). Frame structures can be considered as structures where beams are connected each other to form a skeleton. Beams, beam columns, slabs inside resist against lateral and gravity loads. Similar in the case of the civil engineering applications such like buildings etc., in furniture industry, specifically in the case of simple chair furniture, the legs, the side-rails and the lateral member at the sides of the sitting part forms a frame structure.

Structural analysis methods have been developed in almost last two decades. Just after 1850's, there had been published very beginning of the researches about practical methods for structural analysis and flexure of continuous beams (Rojas, 2012). Maxwell and Castigliano made great contributions to the development structural analysis by using Work and Energy principles in late 19th century. Hardy-Cross who was the Professor at the University of Illinois developed moment distribution method depending on successive steps to determine end moments of segments of a continuous beam (Cross, 1932). Although it was a great method for its age, its applications had some limitations. First, the method does not include deflections caused by axial strains and secondly, and the most important limitation is that the entire lateral movement, side-sway is excluded (Leach, 1960). Slope deflection method is introduced as a publication at 1915 by Maney (Wilson and Maney, 1915). In the furthering years, slope deflection method became a key point to derive the stiffness method which is formulated to be utilized practically by means of matrix systems (Hibbeler, 2008). In the 1950s, developments in structural analysis methods went a step further and extended to finite element analysis.

At the beginning, slope deflection method is applied to the frame structures at which all members are assumed to be Euler- Benoulli beams such that all deformations, e.g. slopes and deflections are assumed to be reasoned by the internal moments such that the deformations by axial or shear forces are neglected. A set of equations is derived by means of the moment area theorems, a contribution by Otto Mohr, and the conjugate beam method, derived by H. Müller-Breslau (Samuelsson and Zienkiewicz, 2006). Moment area theorems state, the area under the curve of the moment diagram between any two nodes related linearly to the change in slope between these points and the flexural rigidity of the member. Equation for each member ending is derived by conjugate beam method such that the moment diagram of the actual case is used as the loading configuration and corresponding shear and moment diagrams refer to slope and deflection through the beam, respectively. Once all equations are solved simultaneously, the internal moments are obtained then all slopes (rotations), θ and deflections (displacements), Ψ are obtained at each node. These equations were enriched by the addition of axial unit deformations and presented as a matrix and computer program to be used in the analysis of multi-storey structures fixed with shear walls (Goldberg, 1967). This method has been used not only to analyze frame structures. Backer et. al. demonstrated an analytical method with slope-deflection formulas for bridge deck analysis. Internal moments in the trapezoidal stiffeners forming the orthotropic bridge deck are determined by this analytical approach (Backer et al., 2008). In another study, slope deflection formulations are derived for the tapered beam-columns to determine the critical buckling loads (Riahi and Etezady, 2012). J.D.A. Ochoa developed 2nd order slope-deflection formulations by including the combined effects of shear and bending deformations and 2nd order axial loading effects on Timoshenko beam supported with semi-rigid connections (Ochoa, 2008; Ochoa, 2010).

The exact analysis of furniture frames is a computationally complex process ow-ing to the large number of internal forces which must be determined in order to make an effective solution. It is very important to use of technological possibilities in strength design of furniture. Today, engineering design of furniture can be accom-plished by utilizing solid modeling and structural analysis softwares. From a practic-ing furniture engineer's point of view, finite element method (FEM) provide the most convenient tool for analyzing the furniture systems. Furniture members, joints, and en-tire of the system can be modelled parametrically via FEM. Then, the strength calcula-tions of the designed members, joints, and the whole system could be made by simu-lating real conditions and loads to solid modelled system, so the stresses at node or member can be obtained.

Recent studies show that the FEM, in the structural analysis of furniture systems and joints has become widespread. A review of the FEM applied in the analysis of furniture constructed with wood materials was given in the study (Tankut and Tankut, 2014).

In the study (Gustafsson, 1997), it was shown how to analyze and design a chair with FEM, and gave the experimental results with stress-strain diagrams of the real chair constructed of Swedish ash (Gustafsson, 1997), also stated that analyzing furniture is a difficult and time-consuming work such that this problem can be solved with FEM software. Kasal, et. al. created analytical models for structural analyses of furniture frames by FEM. It was concluded that analytical models created by FEM give the information concerning the deformations and internal forces on furniture members and joints (Kasal and Puella, 1995). Results of direct stiffness method and FEM for a chair model were compared (Hajdarevic and Busuladzic, 2015). Numerical calculations were performed with the assumption of linear elastic model for orthotropic materials. While both methods gave very good results, it was seen that the direct stiffness method gave more reliable results, especially when semi-solid connections were defined. 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). Laminated wood-based seating furniture was modelled by FEM and stress analyzes and deformations to provide necessary servicability were dissussed (Langová et al., 2019). Size effects on determining the mechanical properties of wooden specimen was emphasized (Hu, et al., 2019), by comparisons of results from experimental and finite element models. The research regarding the numerical and analytical analyses of the withdrawal strength of the T-type mortise and tenon joints was carried out by (Hu and Guan, 2017). In conclusion, it was demonstrated that the consistency level between the withdrawal test results and numerical method was 83%, while it was 80% between the test results and analytical method (Hu and Guan, 2017). A novel joint type is modelled and analyzed (Chen et al., 2022). The stress concentrations on joint reinforcement are well estimated by its finite element model. Ceylan et. al. (2021) analyzed the chair side frame both numerically and experimentally. Radial spring coefficients of individual tenon-mortise joints were determined, then inserted in numerical calculations such that numerical results and experiments fitted well. The other research was carried out to develop a new model of mortise and tenon joint considering the glue line and friction coefficient to analyze the semi-rigid wood joints. The results of the study showed that the developed model of the joint could be applied to analyze the semi-rigid mortise and tenon joint by 85% consistency level (Hu and Guan, 2019). In the other study, three different FEM models used to predict the bending strength of mortise and tenon joints were compared. The results indicated that the semi-rigid model performed much better than the tie rigid model, followed by the whole rigid model (Hu and Liu, 2020). In the study (Hitka et al., 2018), load-carrying capacity and the size of chair joints were studied numerically for chairs on a FEM based software. Legs were constructed by joints where they where attached either with rails or supplemented with braces, or with rails and side stretchers. As it can be understood from the literature, the reliability of the results obtained from the structural analyses is directly related to the correct definition of the materials used in the structural system, and especially the joints into the structural analysis program. In particular, the accuracy in defining the joints affects the force and moment distributions and displacements that will occur in the joints under loading conditions.

Understanding the structural characteristics of furniture depends on the mechanical behavior of the joints used in its construction. Furniture joint can be defined as a certain system that is formed as a result of connecting the ends of the members with appropriate tools and techniques. Furniture joints are semi-rigid connections, and the semi-rigidity coefficient values for each joint type should be determined by experiments.

The behavior of the joints is generally not taken into account in the current structural analysis applied in fields such as civil engineering, especially in steel structures. For this reason, there are two types of connection assumptions at the connections, fully rigid (fixed) or flexible (pinned). It is assumed that all the moment is transferred without any rotation in rigid connections, while in flexible connections there is freedom of rotation and no moment is transferred. However, in practice, a third type of semi-rigid connection, which both makes some rotation and transfers some moment, is encountered. Hence, the concept of a third connection classification, called semi-rigid joint, has emerged (Fig. 1a, b).

In the analysis of large structures as buildings, etc., the connection points constitute a very small place in the structure such that the joint behaves almost fixed.

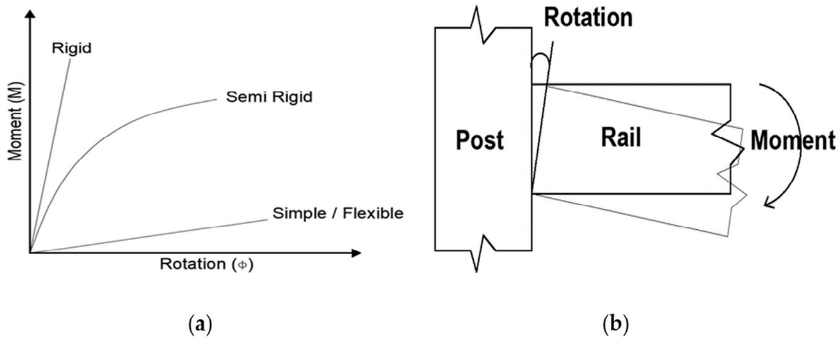

Fig. 1. Rigid, semi-rigid and flexible connections in the moment-rotation relationship (a) and mechanical behavior of semi-rigid connection in the post to rail joint (b)

Contrarily, the joints constitute a larger place in smaller structural systems such as chairs, sofa frames and tables. Therefore, in the structural analysis of furniture, the effects of the mechanical behavior of the joints on the analysis results will be greater. For this reason, it is necessary to define the joints as semi-rigid in the structural analysis of furniture systems.

In this study, slope deflection method is applied to the representative chair side frame for the structural analysis. The chair frame has semi-rigid connections as in the practical applications. Apart from the civil engineering applications, in the case of a furniture frame subjected to sidethrust loads, the joints are exposed to serious angular deformations and lateral displacements (sway), such that the joints cannot keep their rotational rigidity after a limit. Consequently, semi-rigid modelling of connection points would be highly compatible to the case.

The methodology of this paper could be expressed in following sections. Slope deflection equation for a simple beam was derived at section 2. The geometry of the problem, the set of equations were derived for the chair model and results were introduced and discussed, then tables, figures and other outcomes were given in section 3. Conclusions are presented briefly in section 4.

Methods and materials

Angular deformations and lateral displacements are formulated by conjugate beam method. As given in Fig.2a and 2b, moments, M’AB and M’ BA are applied to the ends of the beam, independently, resulting slopes or angular displacements at end A and end B, are derived as (Hibbeler, 2008):

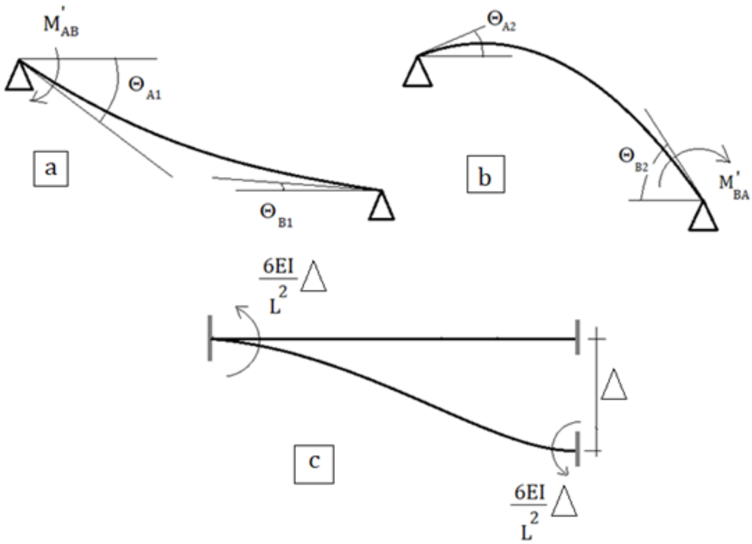

Fig. 2. End rotation at A (a) End rotation at B (b) and lateral displacement at B (c) with corresponding end moments

$$\theta_{A1} = (M'_{AB}L)/3EI \tag{1}$$

$$\theta_{B1} = (M'_{AB}L)/6EI \tag{2}$$

$$\theta_{A2} = (M'_{BA}L)/6EI \tag{3}$$

$$\theta_{B2} = (M'_{BA}L)/3EI \tag{4}$$

These independent angular displacements are superposed such that the angular deformations at both ends are calculated as given:

$$\theta_A = \theta_{A1} - \theta_{A2} \tag{5}$$

$$\theta_B = \theta_{B1} - \theta_{B2} \tag{6}$$

Inserting θ_{A1}, θ_{B1}, θ_{A2} and θ_{B2} into eqn. 5 and 6 will result in a set of equations. The simultaneous solution of them ends up with the end moment equations as given below:

$$M'_{AB} = \frac{2EI}{L}\left(2\theta_A + \theta_B\right) \tag{7}$$

$$M'_{BA} = \frac{2EI}{L}\left(\theta_A + 2\theta_B\right) \tag{8}$$

Finally, end moments, M_{AB} and M_{BA}, are obtained by addition of angular displacement and lateral displacement contributions. Here Δ refers to the lateral displacement (sway) and FEM refers to fixed end moments due to loadings located not exactly to the nodes but between nodes. In this study, load is a point load and applied to a node exactly. End moments are:

$$M_{AB} = M'_{AB} - \frac{6EI}{L^2}\Delta + FEM_A \quad (9)$$

$$M_{BA} = M'_{BA} - \frac{6EI}{L^2}\Delta + FEM_B \quad (10)$$

Results and discussion

Side of the chair is supposed to be a frame structure. AE, FI, BH, CG and DF members form the skeleton (Fig. 3a and 3b). BH, CG and DF members are called side-rails and connected to single piece members, AE and FI by semi-rigid connections.

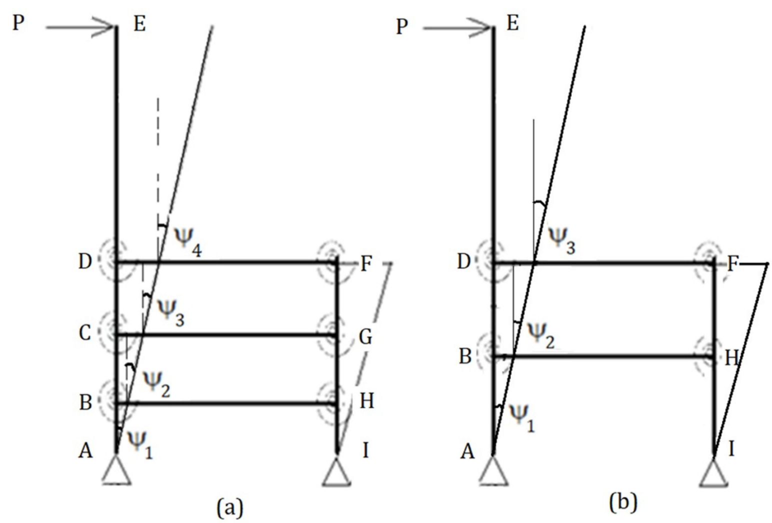

Fig. 3. Model of the chair side frame with a) double side- rails b) single side-rail

It is supported by pin connections at A and I nodes. Semi-rigid connections are modelled by using radial springs, with spring constant k (N-cm/rad), at any arbitrary semi-rigid connection (Fig. 4), the displacement of the node on the vertical member

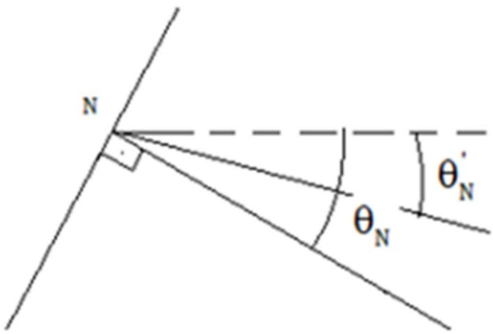

Fig. 4. Angular displacements at an arbitrary node N

(θN) and the displacement of the node on the lateral member (θ›N) are intro-duced sep-arately.

Semi-rigidity is obtained by means of radial linear springs. It is compressed or tensioned at an amount of the difference of these angular dis-placements. Since the frame subject-ed to lateral loading, sway occurs. It is defined by means of individual sway angles Ψ1, Ψ2, Ψ3 and Ψ4,

The angular displacements at each node and sway angles are calculated by the slope deflection equations, the moment equilibrium equations at nodes and the equi-librium of lateral loads. As a result of the force applied from point E, sway will occur in the frame. At the same time, angular displacements will occur at all nodes. Since A and I points are pin connections, there is no need to write a moment formulation here. The moment equilibrium equations for remaining nodes, B, C, D, F, G, and H, can be writ-ten as:

$$M_{BA} + M_{BC} + M_{BH} = 0 \tag{11}$$

$$M_{CB} + M_{CG} + M_{CD} = 0 \tag{12}$$

$$M_{DC} + M_{DF} + M_{DE} = 0 \tag{13}$$

$$M_{HG} + M_{HB} + M_{HI} = 0 \tag{14}$$

$$M_{GF} + M_{GC} + M_{GH} = 0 \tag{15}$$

$$M_{FD} + M_{FG} = 0 \tag{16}$$

Slope deflection equations are constructed for the prescribed moments as shown at eqn.'s 7, 8, 9 and 10. Slope deflection equations are derived for the beam which has fixed ends at both ends. Here, AB and IH members have pin ends at supports and DE has a free end at E, so that MAB, MIH and MED are not calculated and MBA, MHI and MDE are rearranged such that:

$$M_{BA} = 3\frac{E_{BA}I_{BA}}{L_{BA}}\left(\theta_B - \Psi_1\right) \tag{17}$$

$$M_{BC} = 2\frac{E_{BC}I_{BC}}{L_{BC}}\left(2\theta_B + \theta_C - 3\Psi_2\right) \tag{18}$$

$$M_{BH} = 2\frac{E_{BH}I_{BH}}{L_{BH}}\left(2\theta'_B + \theta'_H\right) \tag{19}$$

$$M_{CB} = 2\frac{E_{CB}I_{CB}}{L_{CB}}\left(2\theta_C + \theta_B - 3\Psi_2\right) \tag{20}$$

$$M_{CD} = 2\frac{E_{CD}I_{CD}}{L_{CD}}\left(2\theta_C + \theta_D - 3\Psi_3\right) \tag{21}$$

$$M_{CG} = 2\frac{E_{CG}I_{CG}}{L_{CG}}\left(2\theta'_C + \theta'_G\right) \tag{22}$$

$$M_{DC} = 2\frac{E_{DC}I_{DC}}{L_{DC}}\left(2\theta_D + \theta_C - 3\Psi_3\right) \tag{23}$$

$$M_{DE} = 3\frac{E_{DE}I_{DE}}{L_{DE}}\left(\theta_D + \Psi_4\right) \tag{24}$$

$$M_{DF} = 2\frac{E_{DF}I_{DF}}{L_{DF}}\left(2\theta'_D + \theta'_F\right) \tag{25}$$

$$M_{HI} = 3\frac{E_{HI}I_{HI}}{L_{HI}}\left(\theta_H + \Psi_1\right) \tag{26}$$

$$M_{HG} = 2\frac{E_{HG}I_{HG}}{L_{HG}}\left(2\theta_H + \theta_G + 3\Psi_2\right) \tag{27}$$

$$M_{HB} = 2\frac{E_{HB}I_{HB}}{L_{HB}}\left(2\theta'_H + \theta'_B\right) \tag{28}$$

$$M_{GH} = 2\frac{E_{GH}I_{GH}}{L_{GH}}\left(2\theta_G + \theta_H - 3\Psi_2\right) \tag{29}$$

$$M_{GF} = 2\frac{E_{GF}I_{GF}}{L_{GF}}\left(2\theta_G + \theta_F - 3\Psi_3\right) \tag{30}$$

$$M_{GC} = 2\frac{E_{GC}I_{GC}}{L_{GC}}\left(2\theta'_G + \theta'_C\right) \tag{31}$$

$$M_{FG} = 2\frac{E_{FG}I_{FG}}{L_{FG}}\left(2\theta_F + \theta_G - 3\Psi_3\right) \tag{32}$$

$$M_{FD} = 2\frac{E_{FD}I_{FD}}{L_{FD}}\left(2\theta'_F + \theta'_D\right) \tag{33}$$

Here E is the elasticity constant, I is the moment of inertia of the section, and Ψ is the angular change due to translation. The moment of the semi-rigid connected elements at the nodes can be expressed as follows, in accordance with the linear spring model:

$$M_{BH} = k_B(\theta_B - \theta'_B) \tag{34}$$

$$M_{HB} = k_H(\theta_H - \theta'_H) \tag{35}$$

$$M_{CG} = k_C(\theta_C - \theta'_C) \tag{36}$$

$$M_{GC} = k_G(\theta_G - \theta'_G) \tag{37}$$

$$M_{DF} = k_D(\theta_D - \theta'_D) \tag{38}$$

$$M_{FD} = k_F(\theta_F - \theta'_F) \tag{39}$$

The k constants in the above equations are the spring constant values of the spiral spring used in the model of the semi-rigid element connected at the relevant node.

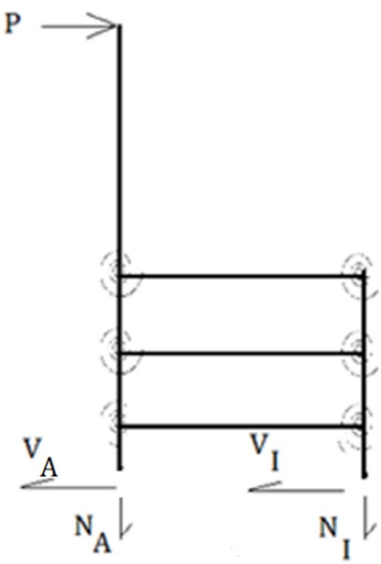

Fig. 5. Free body diagram of the chair side frame with double side-rails

Last three equations can be written according to the shear forces at the vertical members of the system (Fig. 5). Here, since the sum of shear on AB and HI will be equal to the horizontally applied load:

$$P - V_A - V_I = P + \frac{M_{BA}}{L_{BA}} + \frac{M_{HI}}{L_{HI}} = 0 \tag{40}$$

Similar to this, for 2nd and 3rd stages, equations can be derived as:

$$P + \frac{(M_{BC} + M_{CB})}{L_{BC}} + \frac{(M_{GH} + M_{HG})}{L_{GH}} = 0 \tag{41}$$

$$P + \frac{(M_{CD} + M_{DC})}{L_{CD}} + \frac{(M_{GF} + M_{FG})}{L_{GF}} = 0 \tag{42}$$

Eqn.'s 11–42 are solved simultaneously to determine angular deformations, lateral displacements and end moments.

By taking the simpler structure, to focus on the results and to show that the simple problem can be solved with this method, the problem is solved with a single single sid-erail such that the BH element is preserved, while the CG element is removed (Fig. 3b). Here, all elements are identical in cross-sectional sizes and the moments of inertia of the elements are calculated for 60 mm in depth and the 21 mm in width of section di-mensions. The modulus of elasticity is taken as 10 GPa. to illustrate a wooden material. The highest point of the frame is 90 cm, the seat height is 41 cm, the seat depth is 45 cm. and the side-rail is at a height of 21 cm, consequently, AB and HI members are 21 cm, BD and HF are 20 cm, BH and DF are 45 cm and the DE member is 49 cm in length. The force P is taken to be 1000 N. B, D, F and H joints are supposed to be semi-rigid connections such that all these semi-rigid connections linear radial spring coeffients are inserted as kB =kD = kF = kH = C ·105 N-cm/rad where C is an integer from [1, 2, 5, 12, 120, 200, 1000] set. It extends from 1 to 1000 to represent the spring rigidity then high-er values models very rigid connections.

As the C number increases, slopes of lateral members and slopes of vertical members at any same joint converge (Table 1). In the case of very rigid connections, they get closer and closer, e.g. when k is 108 Ncm/rad (C=1000), their ratio approximates to a percentage value between 92 to 96 (Table 2). Sway angles Ψ1, Ψ2 and Ψ3 refers to the these angles at joints B, D and E respectively. They decrease by increasing the stiffness of the semi-rigid connections. While this reduce seems more apparent for the nodes A and B, the sway angle at joint D does not drop as much as at A and B

Table 1. Slopes of vertical members (Θ) and lateral members (Θ’) at nodes B, H, D and F for various C semi-rigid connection constants

Slopes (rad)	C						
	1	2	5	12	120	200	1000
Θ_B	0.2266	0.1141	0.0468	0.0208	0.0046	0.0039	0.0031
Θ'_B	0.0044	0.0043	0.0041	0.0038	0.0031	0.0030	0.0029
Θ_H	0.2287	0.1163	0.0488	0.0227	0.0062	0.0055	0.0046
Θ'_H	0.0045	0.0045	0.0045	0.0046	0.0045	0.0045	0.0044
Θ_D	0.2350	0.1224	0.0547	0.0281	0.0103	0.0095	0.0085
Θ'_D	0.0047	0.0049	0.0054	0.0062	0.0078	0.0080	0.0082
Θ_F	0.2275	0.1150	0.0476	0.0213	0.0042	0.0035	0.0025
Θ'_F	0.0043	0.0041	0.0038	0.0033	0.0025	0.0024	0.0023

Table 2. Ratio of slopes of lateral members (Θ’) to the corresponding slopes of vertical members (Θ) at nodes B, H, D and F for various C semi-rigid connection constants

Ratio (%)	C						
	1	2	5	12	120	200	1000
Θ'_B / Θ_B	1.9	3.8	8.7	18.2	67.4	77.4	94.4
Θ'_H / Θ_H	2.0	3.9	9.3	20.2	72.7	81.6	95.7
Θ'_D / Θ_D	2.0	4.0	9.9	21.9	75.5	83.8	96.3
Θ'_F / Θ_F	1.9	3.6	8.0	15.7	58.0	69.1	91.5

(Table 3). As a result of this, deflections at the B, D and E joints also decreases due to the increase in stiffness (Table 4).

Table 3. Sway angles (Ψ) at nodes A, B and D for various C semi-rigid connection constants

Sway angles (rad)	C						
	1	2	5	12	120	200	1000
Ψ_1	0.2296	0.1171	0.0498	0.0237	0.0073	0.0066	0.0058
Ψ_2	0.2299	0.1174	0.0499	0.0237	0.0068	0.0060	0.0051
Ψ_3	0.2562	0.1436	0.0759	0.0493	0.0315	0.0307	0.0297

Table 4. Deflections at nodes B, D and E for various C semi-rigid connection constants

Deflections (cm)	C						
	1	2	5	12	120	200	1000
Δ_B	4.82	2.46	1.04	0.50	0.15	0.14	0.12
Δ_D	9.42	4.81	2.04	0.97	0.29	0.26	0.22
Δ_E	21.97	11.84	5.76	3.38	1.83	1.76	1.68

To investigate the relationship between the connection rigidity and the displacements at member ends B, D and E, best fit lines are determined (Fig. 6). These lines show the different trends of deflections at member ends B, D and E for the stiffness

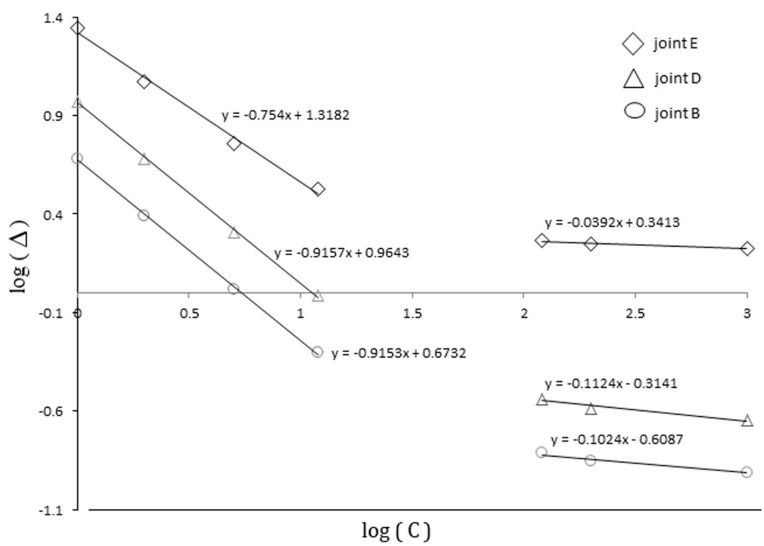

Fig. 6. Semi-rigid joints stiffness vs. the lateral deflection at joints E, D and B in logarithmic scale and the best fit lines

of the connection points before and after some certain values. These values can be obtained by intersection points of referring lines and determined C values are 37.8, 39.0 and 23.3 for B, D and E joints, respectively. Beside that, it is observed from the lines, slope of the line for E is highly less than the slopes of lines B and D such that the deflection at joint E does not decrease as much as at other points (B and D) with the increase of the spring constant.

In Table 5, the end moments are tabulated for C values 1, 2, 5, 12, 120, 200 and 1000. While the rigidity of the semi-rigid connection increases, end moments decrease at all members except for DF member. As the system becomes more rigid with the in-crease in the rigidity at the connection points, all the elements carry less moment, while the resistance against to the horizontal load is provided by DF member by car-rying more and more internal moment. In fact, when the C value is 1000, end moment carried by the DF member is 36 percent more when compared with the case when the C value is 1. It should be noticed that end moment at DE member is 49 kN-cm as usual for all cases.

Table 5. Moments (kN-cm) at member ends for various C semi-rigid connection constants

C	M_{BA}	M_{BH}	M_{BD}	M_{DB}	M_{DF}	M_{DE}	M_{FH}	M_{FD}	M_{HI}	M_{HB}	M_{HF}
1	–16.34	22.22	–5.88	25.97	23.03	–49.00	–22.32	22.32	–4.66	22.43	–17.76
2	–16.22	21.97	–5.75	25.50	23.50	–49.00	–22.18	22.18	–4.78	22.35	–17.57
5	–15.95	21.36	–5.41	24.37	24.63	–49.00	–21.88	21.88	–5.05	22.14	–17.09
12	–15.57	20.41	–4.84	22.69	26.31	–49.00	–21.55	21.55	–5.43	21.73	–16.30
120	–14.81	17.93	–3.13	18.62	30.38	–49.00	–21.40	21.40	–6.19	20.29	–14.09
200	–14.74	17.67	–2.93	18.22	30.78	–49.00	–21.44	21.44	–6.26	20.11	–13.85
1000	–14.66	17.31	–2.66	17.67	31.33	–49.00	–21.50	21.50	–6.34	19.86	–13.51

Conclusions

In this study, a representative chair side frame was structurally analyzed by using slope-deflection method. Connections in the system were assumed to be semi-rigid in the structural analyses. By reducing and increasing the stiffness/rigidity of joints, the displacements were evaluated.

Furniture frames are exposed large lateral deflections (sway) in practical use due to semi-rigid connections in general. The analysis of such frames would require in-cluding not only the rotations at joints but also the lateral displacements in the present case. In Tables 1–4, it is shown that, reasonable amount of lateral displacements are ob-tained when the representative chair frame is subjected to almost twice of house-use load and increasing rigidity in the joints causes less sway. In addition to this, as shown in Table-5, by increasing stiffness at connections, end moments reduces slightly at all members except for DF which is the top side lateral member that is subjected to more bending moment. In fact, when the most flexible and rigid cases those when C is 1 and 1000, respectively, are compared, the lateral displacement at the E point decreases by almost 90 percent, while the end moment in the DF member increases by 36 percent, approximately.

A chair, as a furniture, is subjected to considerable lateral displacements related with the rigidity of the connections. Due to lateral displacements, a possible failure can occur probably at the connection points. Because of that, to determine moments at member ends becomes key, at that point. Consequently, it can be concluded that slope-deflection method is very efficient in furniture analysis, a very convenient meth-od to perform the structural analysis, especially of such a frame structure under lateral loading. Present mathematical formulations can be extended more by consid-ering the second order effects, such like axial and shear deformations.

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References

Backer, H.D., Outtier, A., Bogaert, P.V. (2008). Analytical calculation of internal forces in orthotropic plated bridge decks based on the slope-deflection method. Journal of Constructional Steel Research, 64, 1530–1539. 10.1016/J.JCSR.2008.01.009

Ceylan, E., Güray, E., Kasal, A., Ceylan, E., Güray, E., Kasal, A. (2021). Structural analyses of wooden chairs by finite element method (FEM) and assessment of the cyclic loading performance in comparison with allowable design loads. Maderas: Ciencia y Tecnología, 23, 1–16. 10.4067/S0718-221X2021000100419

Chen, B., Yu, X., Hu, W. (2022). Experimental and numerical studies on the cantilevered leg joint and its reinforced version commonly used in modern wood furniture. BioResources 17, 3952–3964. 10.15376/BIORES.17.3.3952-3964

Cross, H. (1932). Analysis of continuous frames by distributing fixed-end moments. Transactions of the American Society of Civil Engineers, 96, 1–10, 10.1061/TACEAT.0004333

Eckelman, C. (2003). Textbook of product engineering and strength. Purdue University. West Lafayette, Indiana, USA.

Goldberg, J.E. (1967). Analysis of multistorey buildings considering shear wall and floor deformations. In: Tall buildings. The proceedings of a symposium on tall buildings with particular reference to shear wall structures, held in the department of civil engineering, University of Southampton, April 1966 (pp. 349–375). 10.1016/B978-0-08-011692-1.50021-3

Gustafsson, S.I. (1997). Optimising ash wood chairs. Wood Science and Technology, 31, 291–301. 10.1007/BF00702616

Hajdarevic, S., Busuladzic, I. (2015). Stiffness analysis of wood chair frame. Procedia Engineering, 100, 746–755. 10.1016/J.PROENG.2015.01.428

Hibbeler, R.C. (2008). Structural analysis (9th ed.). Prentice Hall.

Hitka, M., Joščák, P., Langová, N., Krišťák, L., Blašková, S. (2018). Load-carrying capacity and the size of chair joints determined for users with a higher body weight. BioResources, 13, 6428–6443. 10.15376/biores.13.3.6428-6443

Hu, W., Guan, H. (2019). A finite element model of semi-rigid mortise-and-tenon joint considering glue line and friction coefficient. Journal of Wood Science, 65, 1–9. 10.1186/S10086-019-1794-4

Hu, W., Liu, N. (2020). Comparisons of finite element models used to predict bending strength of mortise-and-tenon joints. BioResources, 15, 5801–5811. 10.15376/biores.15.3.5801-5811

Hu, W., Wan, H., Guan, H. (2019). Size effect on the elastic mechanical properties of beech and its application in finite element analysis of wood structures. Forests, 10(9), 783. 10.3390/F10090783

Hu, W.G., Guan, H.Y. (2017). Research on withdrawal strength of mortise and tenon joint by numerical and analytic methods. Wood Research, 62, 575–586.

Kasal, A. (2004). The strenght performance of sofa frames constructed of solid wood and wood composites. Graduate School of Natural and Applied Sciences Institute of Science Phd. Thesis. Gazi University: Ankara.

Kasal, B., Puella, S.V. (1995). Development of analytical models for furniture technical report 95-01. Furniture Manufacturing and Management Center.

Langová, N., Réh, R., Igaz, R., Krišt'ák, L., Hitka, M., Joščák, P. (2019). Construction of wood-based lamella for increased load on seating furniture. 10, 525. 10.3390/F10060525

Leach, R. (1960). An analytical study of a space frame. Houston, Texas, US: Rice University.

Luevanos Rojas A. (2012). Method of structural analysis for statically indeterminate beams. International Journal Of Innovative Computing, Information & Control, 8, 5473–5486.

Ochoa, J.D.A. (2010). Second-order slope–deflection equations for imperfect beam–column structures with semi-rigid connections. Engineering Structures, 32, 2440–2454, 10.1016/J.ENGSTRUCT.2010.04.018

Ochoa, J.D.A. (2008). Slope-Deflection Equations for Stability and Second-Order Analysis of Timoshenho Beam–Column Structures with Semi-Rigid Connections. Eng. Struct. 2008, 30, 2517–2527. 10.1016/J.ENGSTRUCT.2008.02.007

Riahi, H.T., Etezady, S.M. (2012). A buckling analysis of non-prismatic columns using slope-deflection method – The institute of theoretical and applied mechanics. In: Proceedings of the buckling analysis of non-prismatic columns using slope-deflection method; Proceedings of the 15th World Conference on Earthquake Engineering: Portugal (pp. 28700–28709). https://www.iitk.ac.in/nicee/wcee/article/WCEE2012_5315.pdf

Samuelsson, A., Zienkiewicz, O.C. (2006). History of the stiffness method. International Journal for Numerical Methods in Engineering, 67, 149–157. https://doi.org/10.1002/nme.1510

Smardzewski, J. (1998). Numerical analysis of furniture constructions. Wood Science and Technology, 32, 273–286. 10.1007/BF00702895

Tankut, N., Tankut, A.N., Zor, M. (2014). Finite element analysis of wood materials. Drvna Industrija, 65, 159–171. 10.5552/DRIND.2014.1254

Wilson, W.M., Maney G.A. (1915). Slope-Deflection Method. Univ. Illinois Eng. Exp. Station. Bull.