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STUDY OF THE BENDING MODULUS OF ELASTICITY OF EDGE GLUED WOODEN PANELS WITH DIFFERENT WIDTH JOININGS

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Abstract

Edge glued wooden panels (EWPs) are the wood-based panels the closest to natural wood. The fact that EWPs do not have chemicals that are harmful to the environment and human health in their structures and that they do not lose the texture of wood, has drawn the attention of consumers in recent years. The other panels based on wood become bended and deformed in places that are continuously subjected to a static load effect, especially in chest-type furniture. In this study, the width joinings of the edge glued wooden panels were examined for the elasticity characteristic under the influence of this type of load. Consequently, besides the flat width joinings, which are the present production form, finger joint and triangular cut width joinings were studied. In conclusion, the panels on which flat width joinings were made had the best modulus of elasticity values.

Keywords: Width joining, Edge Glued Wooden Panel, Bending Modulus of Elasticity

1. Introduction

The use of wooden materials produced by passing through a series of procedures that we can call synthetic wood started to become widespread with the increase in technological opportunities, especially after the 1950s. Wooden materials in various shapes can be utilized together with scraps with these procedures. Especially, large-sized synthetic wooden panels are produced, which are impossible to obtain naturally [1]. Plywood, oriented strand board (OSB), chipboard and medium-density fiberboard (MDF) are examples of these materials. It is observed that some resistance weaknesses occur unexpectedly in the processing and use of these materials [2]. Although desirable, it has been impossible to completely obtain the output and quality of natural solid wood with the panels produced with various methods. Furthermore, the fact that the panels produced contain chemicals that are harmful to the environment and human health, has prevented their use as furniture and decoration materials, especially in the developed countries [3]. One of the materials developed for being able to overcome these problems and for being able to well utilize wood is the composite called "edge glued wooden panels" (EWPs), which have the characteristics of layered wooden-based materials and the use of which has also become widespread in Turkey, especially in recent years.

EWPs are wooden panels obtained from wood species having the same type and characteristics, that have been purified of defects, are in long, narrow strips of wood or narrow and thick wood dimensions, which are obtained by gluing side-by-side in a suitable technique or by adding end-to-end or in a single piece [4]. EWPs with their production form are the materials having the closest characteristics to natural solid wood. They are preferred as environmentally-friendly materials, since they do not contain harmful chemicals and as adhesives are used that do not harm the environment and human health [5]. It has been stated in the studies made that the EWPs produced can be used in dry and humid weather conditions as load carrying construction materials, such as in the construction of door and window woodworks and beams, other than in the production of furniture [6]. It has been observed that composite materials under a static load in the load carrying elements, such as shelves in particular, have a lower resistance to deformation compared to natural wooden materials [7]. Consequently, EWPs as the closest material to natural wood, could be preferred in

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places where elastic deformation is observed, such as in furniture shelves.

Shelves in furniture are subjected to various constraints and loads according to their purpose and the place they are used. Consequently, the material for making furniture, the type of joining used and the resistance against static and dynamic forces in their entire construction are very important [8].

Elasticity is a characteristic of resuming the original shape when the force that changes the shape of an object under the influence of an external force is removed [9]. Elastic characteristics are valid under a definite limit in solid substances. Above this limit, plastic deformation or breaking occurs. If the deformations increase, then the wood-like structural elements can break quickly, because accumulating the tensions, as in steel, is not under consideration [10]. Furthermore, structural characteristics, such as the density and fiber structure of the wooden materials are also important factors in the elasticity characteristic. In the study made, it was shown that the solid material did not have a difference in the bending modulus of elasticity up until a fiber curvature of 15% [11].

The elasticity characteristic of wooden materials is important in places where it remains under a static load, such as a bookshelf. Deformation by bending downwards connected to the influence of a load within time by wood-based panels is an undesirable situation and is frequently encountered.

While finger-joints are applied in the end-to-end additions in EWP production, flat joinings are made without application of any joint form in the side-by-side length joinings. This situation creates some problems in the elasticity resistance. In the studies made, resistance problems were observed under the influence of a static load on the EWPs made with the existing production [12]. The stability and endurance of furniture under load is connected to the physical and mechanical characteristics of the materials produced and to the joining techniques of the pieces forming the furniture [7]. In this study, different constructions were attempted in the side-by-side length joinings for increasing the bending elasticity characteristics of the edge glued wooden panels and the elasticity characteristics for the use of EWPs in places where the static load effects were observed have been studied.

2. Materials and Methods

2.1. Materials

Oriental beech (*Fagus orientalis* L.), Uludağ fir (*Abies bornmülleriana* Mattf.) and Calabrian pine (*Pinus brutia* Ten.) woods, which are extensively found in Turkey, were used in this study.

The PVA – D3 adhesives, Kleiberit 303 and Dorus – MD073, which are suitable for the cold pressing procedure and which are not harmful to human health and the environment, were used in the preparation of the test specimens.

The Kleiberit 303 adhesive is a glue that can be applied as a single or double component and hot or cold. Its viscosity value is 13,000 ± 2,000 Mp at 20ºC, its pH value is ~3, its freezing point is -30ºC and its lowest film formation temperature is +10ºC [13]. The Dorus MD 073 adhesive is a water-resistant glue for assemblage that has a PVAc dispersion characteristic. Its viscosity value is 13,000 mPas, its pH value is ~3.5 and its lowest film formation temperature is +5ºC [14].

2.2. Preparation of the test specimens

The preparation of the test specimens started with the production of the panels. First of all, the long, narrow strips of wood forming the panels were produced in three different width cuts (flat, finger and triangular) (Figure 1) and were kept in a climatization chamber in an environment at a temperature of 20±2ºC and relative humidity of 65±5% until they reached a balanced humidity of 12±0.5%. Subsequently, the long, narrow strips of wood were classified according to their characteristics, cutting directions and directions of annual rings. The adhesives used were applied in the amounts of 150-160 g/m^2 with a brush in a manner that would constitute an equal layer on a single side of the bonding surface between the long, narrow strips of wood according to the TS 4315 and prEn 386 standards. The glued long, narrow strips of wood taken for the pressing process were kept for 30 minutes under workshop conditions in the cold press in the horizontal pressing equipment prepared especially for this study. The panels removed from the press were cut to the dimensions of 900x900x21 mm, which was suitable for the test conditions.

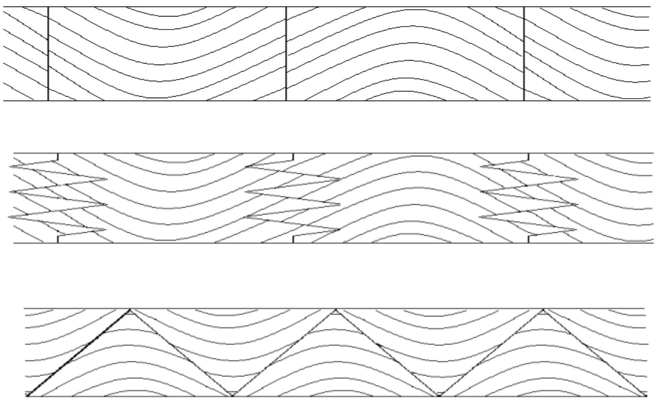

Figure 1. Edge glued panel specimens produced: (a) Flat width joining, (b) Finger width joining, (c) Triangular width joining

Accordingly, two different cutting directions (tangential, radial), three different wood species (Oriental beech, Uludağ fir, Calabrian pine), two different types of adhesive (Kleiberit 303, Dorus MD 073) and three different width joining types (flat, finger, triangular cuts) were implemented in the EWP production. A total of 180 each EWPs were produced with 5 each wood panels for 36 each variables in the dimensions of 90x90 cm.

Specimens from the panels were prepared for the determination of the bending modulus of elasticity according to the TS 11971 standards in the dimensions of 22x50x320 mm and in a manner so that the force applied would be at the joining place on the central axis [15]. A total of 360 each test specimens were prepared according to the TS EN 326-1 standard, with 2 each from every panel and 10 each for every panel type.

2.3. Methods

The specimens were brought to a balanced humidity of 12% and the determination of the bending modulus of elasticity was made according to the TS 11971 standards. The bending resistance tests were made on the test specimens in the compression-tension test machine according to the standards.

The equation given below was used in the determination of the modulus of elasticity with the aid of the bending difference (Δf) in the specimens for the force difference (ΔF) implemented in the elastic deformation region:

$$E = \frac{\Delta F . l^3}{4.b.h^3 . \Delta f} \qquad [1]$$

Here:
(E) = Modulus of elasticity in bending (N/mm^2)
(l) = Distance between fulcrums (mm)
b = Breadth of the width cut of the test piece (mm)
h = Thickness of width cut (mm)

2.4. Evaluation of the data

The multiple analysis of variance (MANOVA) was implemented for the data obtained at the end of the tests. As a result of the analyses of variance, when the difference among groups was significant, a two-way comparison was made with the least significant difference (LSD) test for the factors within the groups. The MSTAT-C package program was used in the statistical analyses of the data obtained with the measurements.

3. Findings and Discussion

The averages values obtained at the end of the bending modulus of elasticity parallel to the fibers have been given in Table 1 and the results of the MANOVA made to determine the variables, which caused the differentiations, have been given in Table 2.

Table 1. Average values of bending modulus of elasticity (N/mm^2)

SOURCE				Bending Modulus of Elasticity (N/mm^2)	
Wood Species	**Cutting Direction**	**Joining Type**	**Adhesive Type**	$\bar{X}$	**s**
Fir (G)	Tangential (T)	Flat Width (D)	Dorus MD073 (D)	7919,12	1004,32
			Kleiberit 303 (K)	7768,39	1762,00
		Triangular Strip of Wood (Ü)	Dorus MD073 (D)	7312,82	725,16
			Kleiberit 303 (K)	7380,72	1321,49
		Serrated Width (K)	Dorus MD073 (D)	8474,46	984,34
			Kleiberit 303 (K)	9995,36	1468,58
	Radial (R)	Flat Width (D)	Dorus MD073 (D)	8726,65	545,25
			Kleiberit 303 (K)	9599,02	1329,16
		Triangular Strip of Wood (Ü)	Dorus MD073 (D)	7932,06	1131,14
			Kleiberit 303 (K)	7633,83	1093,06
		Serrated Width (K)	Dorus MD073 (D)	7937,99	1105,50
			Kleiberit 303 (K)	9026,78	954,56
Beech (K)	Tangential (T)	Flat Width (D)	Dorus MD073 (D)	17400,11	936,51
			Kleiberit 303 (K)	16911,12	2517,21
		Triangular Strip of Wood (Ü)	Dorus MD073 (D)	14131,29	1074,57
			Kleiberit 303 (K)	12982,66	1018,47
		Serrated Width (K)	Dorus MD073 (D)	14192,28	1574,68
			Kleiberit 303 (K)	16019,35	1681,73
	Radial (R)	Flat Width (D)	Dorus MD073 (D)	13533,97	767,44
			Kleiberit 303 (K)	12668,62	1725,68
		Triangular Strip of Wood (Ü)	Dorus MD073 (D)	11713,77	588,47
			Kleiberit 303 (K)	11099,03	1064,05
		Serrated Width (K)	Dorus MD073 (D)	13381,14	917,47
			Kleiberit 303 (K)	13175,99	2715,82
Pine (Ç)	Tangential (T)	Flat Width (D)	Dorus MD073 (D)	11439,82	1166,12
			Kleiberit 303 (K)	10608,87	1434,63
		Triangular Strip of Wood (Ü)	Dorus MD073 (D)	8495,09	2874,51
			Kleiberit 303 (K)	10755,71	1228,26
		Serrated Width (K)	Dorus MD073 (D)	9700,90	626,75
			Kleiberit 303 (K)	10272,8	2304,16
	Radial (R)	Flat Width (D)	Dorus MD073 (D)	10403,29	1782,52
			Kleiberit 303 (K)	12711,26	1840,26
		Triangular Strip of Wood (Ü)	Dorus MD073 (D)	12987,48	2162,49
			Kleiberit 303 (K)	13175,88	1259,29
		Serrated Width (K)	Dorus MD073 (D)	11071,90	995,02
			Kleiberit 303 (K)	11232,82	1929,62

$\bar{X}$: Average   *s*: Standard Deviation

Table 2. Multiple analysis of variance (MANOVA) for bending modulus of elasticity

Source	Sum of Squares	Degree of Freedom	Mean Square	F	P
CuttingDirection (A)	3905036,346	1	3905036,346	1,744	0,188^{NS}
Wood Species (B)	1898758394,007	2	949379197,004	424,094	0,000
Joining Type (C)	84592514,270	2	42296257,135	18,894	0,000
Adhesive Type (D)	10899630,356	1	10899630,356	4,869	0,028
A x B	303068506,403	2	151534253,201	67,691	0,000
A x C	29043221,775	2	14521610,887	6,487	0,002
B x C	110437192,419	4	27609298,105	12,333	0,000
C x D	10405164,615	2	5202582,307	2,324	0,100^{NS}
A x D	274508,908	1	274508,908	,123	0,726^{NS}
B x D	17065842,608	2	8532921,304	3,812	0,023

A x B x C	68844604,218	4	17211151,054	7,688	0,000
A x B x D	3054667,800	2	1527333,900	,682	$0{,}506^{NS}$
A x C x D	21580259,410	2	10790129,705	4,820	0,009
B x C x D	20816656,934	4	5204164,234	2,325	$0{,}056^{NS}$
A x B x C x D	25690590,059	4	6422647,515	2,869	0,023
Error	725308550,772	324	2238606,638		
Total	47727605339,109	360			

(*NS*) Difference in statistical is insignificant which should P > 0,05.

When the average values in Table 1 are considered, it was observed that the highest bending modulus of elasticity values were obtained in the panels produced with Oriental beech wood. According to the analysis of variance results, it was found that there was no effect of cutting direction on the modulus of elasticity (p > 0.05).

From the two-way influence groups, a statistically significant effect on the modulus of elasticity was not observed between the *joining type x type of adhesive* and the *cutting direction x type of adhesive* groups. Furthermore, from the three-way influence groups, an influence on the modulus of elasticity was not observed between the *cutting direction x wood species x adhesive type* and the *wood species x joining type x adhesive type* groups at the 5% level of significance.

The comparison results made to determine the least significant difference (LSD) towards each other within the group of all variables in which a significant relationship emerged among them have been given in Table 3 and Table 4.

Table 3. The Duncan test comparison results for bending modulus of elasticity with all of the variables groups (N/mm^2)

Wood Species	$\bar{X}$	*HG*	**Joining Type**	$\bar{X}$	*HG*	**Adhesive Type**	$\bar{X}$	*HG*
Fir (G)	8308,932	C	Flat Width (D)	11640,852	A	Dorus MD073 (D)	10930,784	B
Beech (K)	13934,109	A	Triangular Strip (Ü)	10466,694	C	Kleiberit 303 (K)	11278,788	A
Pine (Ç)	11071,317	B	Serrated Width (K)	11206,813	B	LSD ± 462,495		
LSD ± 566,445			LSD ± 566,445					

$\bar{X}$: Average HG : Group of Homogeneity

Table 4. The Duncan test four-way comparison results at the level of wood species – cutting direction – joining type – adhesive type (N/mm^2)

SOURCE					
Wood Species	**Cutting Direction**	**Joining Type**	**Adhesive Type**	$\bar{X}$	*HG*
G	T	D	D	7919,124	KL
			K	7768,391	KL
		Ü	D	7312,815	L
			K	7380,716	L
		K	D	8474,458	JKL
			K	9995,359	FGHIİ
	R	D	D	8726,646	İJKL
			K	9599,019	HIİJ
		Ü	D	7932,064	KL
			K	7633,834	KL
		K	D	7937,988	KL
			K	9026,777	IİJK
K	T	D	D	17400,105	A
			K	16911,119	A
		Ü	D	14131,292	B
			K	12982,663	BC

		K	D	14192,282	B
			K	16019,350	A
	R	D	D	13533,965	B
			K	12668,617	BCD
		Ü	D	11713,765	CDE
			K	11099,025	EFGH
		K	D	13381,139	B
			K	13175,988	BC
Ç	T	D	D	11439,821	DEF
			K	10608,865	EFGH
		Ü	D	8495,090	JKL
			K	10755,712	EFGH
		K	D	9700,900	GHIİJ
			K	10272,800	EFGHI
	R	D	D	10403,289	EFGHI
			K	12711,264	BCD
		Ü	D	12987,476	BC
			K	13175,876	BC
		K	D	11071,896	EFGH
			K	11232,817	EFG
LSD ± 1962,251					

According to the LSD test results, the highest modulus of elasticity value was found in the Oriental beech wood from the aspect of *wood species*, in the flat width joining type from the aspect of *joining type* and in the Kleiberit 303 adhesive from the aspect of *adhesive type*. Here, the fact that the flat joining type produced a better result compared to the finger joining type is a significant result.

Finally, at the *wood species – cutting direction – joining type – adhesive type* interaction level, the four-way comparison results made to determine the least significant differences have been given in Table 4.

According to the four-way comparison results made to determine the least significant differences among the variables given in Table 4, the highest modulus of elasticity values were observed in the Oriental beech wood – tangential cut – flat joining – Dorus MD073 adhesive, in the Oriental beech wood – tangential cut – flat joining – Kleiberit 303 adhesive and the Oriental beech wood – tangential cut – finger joining – Kleiberit 303 adhesive groups. Accordingly, it can be stated that the wood species and cutting direction variables had not a greater influence on the bending modulus of elasticity.

4. Results

The elasticity characteristics against static loads that could be encountered during the use of edge glued wooden panels (EWPs), which have been in demand in furniture production in recent years, were investigated in this study. Despite the fact that it was stated in the literature that the modulus of elasticity in a radial direction of the wooden materials was approximately two-fold greater compared to the tangential direction, according to the results of the study, it was observed that the cutting direction did not have an influence in the determination of the bending modulus of elasticity [16].

Furthermore, the flat width joinings produced better results compared to the finger and triangular width joinings. According to this result, in chest-type furniture under the influence of static load, it can be stated that a problem will not emerge from the aspect of bending deformation when the flat width joining method is used, which is applied in the present production. According to the study made, in case EWP is preferred in the places where it could be subjected to elastic deformation in the production of furniture, panels made from hardwood trees and with flat width joinings could be preferred.

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