Technology, 12(4), 235-243,(2009)

TECHNOLOGY

STUDY OF THE BENDING RESISTANCE IN A DIRECTION PARALLEL TO THE FIBERS OF EDGE GLUED WOODEN PANELS (EWP) PRODUCED WITH DIFFERENT CONSTRUCTIONS

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Abstract

Some problems in resistance characteristics are caused by not applying width joining in the production of Edge Glued Wooden Panels (EWP). In this study, it was aimed to increase the bending resistance in a direction parallel to the fibers by studying different solutions in the side-by-side width joinings of the strips of wood in EWP production. For this, EWPs were obtained with the width joining method by bonding in a tangential and radial cut direction with Kleiberit-303 and Dorus-MD 073 adhesives on the flat, serrated and triangular shaped strips of wood from Oriental beech (*Fagus orientalis* L.), Uludağ fir (*Abies bornmülleriana* Mattf.) and Calabrian pine (*Pinus brutia* Ten.) woods. Bending tests were made by taking specimens from the panels obtained according to TS 11971. In conclusion, the Oriental beech-radial-serrated-Dorus interaction in the bending resistance in a direction parallel to the fibers produced the best result (16.39 N/mm^2).

Keywords: Edge Glued Wooden Panel, Construction, Bending resistance

1. Introduction

Forest assets are rapidly decreasing due to increasing population density and the careless use of raw materials. Consequently, studies are being made continuously for the economic use of wood and for increasing the characteristics of wood-based panel materials. The use of edge glued wooden panels (EWPs), which are in the forefront with their characteristics, has become widespread in recent years. The edge glued wooden panels (EWPs) are wooden panels obtained from wood species of the same type or characteristics that have been bonded side-by-side with an appropriate technique in the form of end-to-end connections or a single piece of the edge glued wooden materials from the strips of wood or thin strips of wood dimensions that are purified of defects [1]. Since EWP is developed with the logic of rejoining the width and length after purifying the defects from natural wood, it is the panel material having the closest characteristics to natural solid wood. In the studies made, the shearing resistance of the EWPs produced was examined under dry and humid climatic conditions. The view emerged that besides the production of furniture, EWP was also usable as a construction material, such as for door and window frames and in the construction of beams [2]. One of the most significant advantages of using EWP in the furniture industry is the possibility of being able to increase the measurements of the EWPs, especially in width, without additional cost, in contrast to the product design necessity according to the panel (such as MDF and plywood) in the other wooden-based panels. Thus, it prevents excessive waste [1].

After making the slicing process of the strips of wood for the EWPs, the inferior quality parts, such as the fiber defects, knots, splits, discolorations and suberizations, are removed and are rebonded. In the production of panels, the sliced solid strips of wood are lined up side-by-side in a manner in which the fiber directions are parallel to each other and by using a polymer-based adhesive, are bonded under a specific temperature

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and pressure. Thus, a material, which is purified from defects and in larger dimensions, is obtained and can be reprocessed [3]. The panels made in the present-day production are applied as serrated joinings in length and flat joinings are made to the strips of wood in width. The reason for this is the thought that there would not be an excessive resistance difference between the formed joints [4]. The D3 class PVAc dispersion adhesives, which have a water-resistant characteristic and which do not harm the environment and human health, are used during the joinings according to the BS-EN 204 standard. In a study made related to this, the 25 mm sharp serrated specimens that were bonded with Kleiberit 303 adhesive, which is a PVAc adhesive, showed the highest bending resistance in the joinings [5]. Furthermore, the application of the serrated directions horizontally produced a better result for the bending resistance compared to the serrated opening in a vertical direction [6].

Some problems in the mechanical and physical characteristics are caused in case width joinings are not applied in EWP production. Humidity amounts other than 12-16%, which is suitable for EWP, decreases the resistances [7]. Furthermore, it was determined that 1% humidity changes are influential on the head sections of the panels and that it should be followed carefully [8]. It was observed that openings in a parallel direction occur in the fibers, especially together with humidity changes. By taking these problems under consideration, it was determined that there was no study in the literature on the subject of increasing joining resistance in width and that it was not discussed sufficiently and that the EWP materials, as a perfect and healthy material, could be an alternative to the other wood-based panels. In this study, it was aimed to develop alternative structures to the existing production to increase the bending resistance by researching different solutions in the side-by-side width joinings of the strips of wood in EWP production and it was desired to become an innovator on this subject in the literature.

2. Material and Metod

2.1 Metarial

2.1.1 Wooden Materials

Oriental beech (*Fagus orientalis* L.), Uludağ fir (*Abies bornmülleriana* Mattf.) and Calabrian pine (*Pinus brutia* Ten.) woods were used in this study. These wood species were preferred, because they are the most used woods in Turkey. Some of the physical and mechanical characteristics of these woods are given in Table 1.

Table 1. Some physical and mechanical characteristics of the woods used in the study [9,10,11,12]

Characteristics	Wood Species		
	Oriental Beech	**Uludağ Fir**	**Calabrian Pine**
Density (Oven dry) (g/cm^3)	0.63	0,40	0,53
Density (Air dry) (g/cm^3)	0.66	0,43	0,57
Compressing Strength (//) (kg/cm^2)	620	374	447
Bending Strength (kg/cm^2)	1070	730	821,5
Modulus of Elasticity in Bending (kg/cm^2)	125000	83000	90000

2.1.2 Adhesives

Kleiberit 303 and Dorus MD 073 adhesives, of the PVA-D3 adhesives, which are suitable for the cold pressing process and which do not harm human health and the environment, were used in the preparation of the test specimens. The adhesives were used according to the instructions of the manufacturer.

The Kleiberit 303 adhesive is an adhesive with a single or double component and which can be applied either hot or cold. The viscosity value is 13,000+2,000 mPas at 20^{o}C, its pH value is ~3, its freezing point is -30^{o}C, its lowest film formation temperature is +10^{o}C and its open life is 6-10 minutes at 20^{o}C [13].

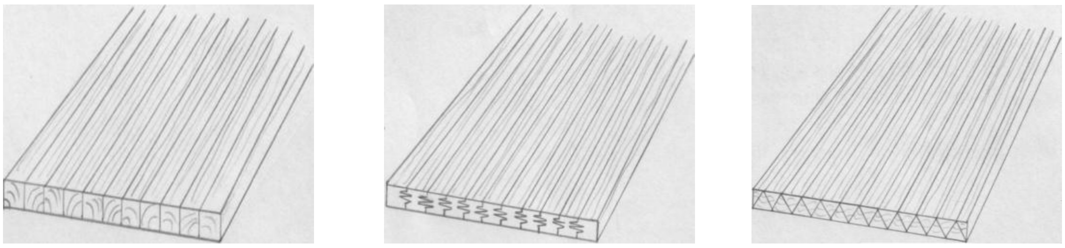
The Dorus MD 073 adhesive is a D3 class water-resistant adhesive having a PVAc dispersion characteristic for assembly. Its characteristic features are the fact that it has a medium viscosity, a rapid hardening characteristic and that it has a long open time period. The viscosity value is 13,000 mPas, the pH value is ~3.5, it lowest film formation temperature is +5^{o}C and its open life is ~11 minutes at 20^{o}C [14].

2.1.3 Preparation of the test specimens

The preparation of the test specimens was started with the production of the panels. First of all, the strips of wood forming the panels were produced in three different width cuts (flat, serrated and triangular). The strips of wood were kept at a temperature of 20±2°C and a relative humidity of 65±5% until they reached a humidity of 12±0.5%. Subsequently, the strips of wood prepared were joined according to their characteristics, cutting directions and annual ring directions and the pressing process was made by applying the adhesive in the amount of 150-160 g/m^2 with a brush in a manner that would form an equal layer on a single side of the bonding surface according to the TS 4315 and prEN 386 standards. After continuing the cold pressing for 30 minutes under workshop conditions (temperature of 20±2°C and relative humidity of 65±5%) it was ended. A special horizontal pressing equipment was produced to be used in this study for the pressing process. The panels removed from the press were cut to the measurements of 900x900x21 mm in accordance with the test conditions (Fig. 1).

According to this, two different cutting directions (tangential and radial), three different wood species (Oriental beech, Uludağ fir and Calabrian pine), two PVA adhesives (Kleiberit 303 and Dorus MD 073) and three different width cut joint types (flat, serrated and triangular cuts) were implemented in the EWP production. A total of 180 each EWPs were produced with 36 variables and 5 each wooden panels with the dimensions of 90x90 cm from each variable. The panels produced were kept at a temperature of 20±2°C and a relative humidity of 65±5% until they reached a humidity of 12±0.5%.

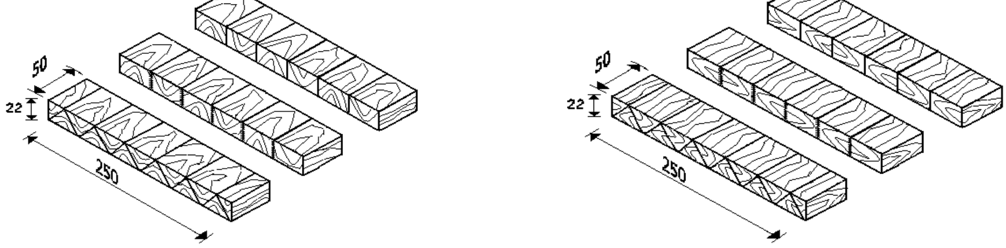
Subsequently, the test specimens needed from each panel were obtained in conformance with the TS 2756-0 (ISO 2859-0) and the TS 53 standards. When obtaining the test specimens, conditions that could influence the results of the tests were taken into account, such as not having knots and resin, fiber defects and not having defects on the bonding surface.



(a) (b) (c)

Figure 1. Specimens of edge glued wooden panels produced: (a) Flat width joining, (b) Serrated width joining, (c) Triangular strip of wood width joining

Specimens from the panels were prepared in the dimensions of 22x50x250 mm and in a manner where the joining place of the force applied would be at the central axis (Fig. 2). A total of 360 each specimens were prepared in a manner in which there would be 10 each for each lot.



(a) (b)

Figure 2. Test specimens: (a) with tangential cut surface, (b) with radial cut surface

2.2 Methods

The specimens on which the bending test would be applied in a direction parallel to the fibers were brought to a balanced humidity of 12±2% in a climatization chamber with a temperature of 20±2°C and a relative humidity of 65±5%. As it can be seen in Fig. 3, the test specimens were placed in the test equipment and the tests were made according to TS 11971 [15].

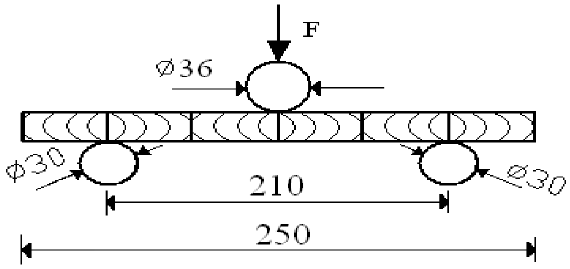


Figure 3. Test mechanism (measurements are in mm)

The distance between the fulcrums was determined to be 210 mm and the force was applied at a speed of $2x10^{-4}$ mm/sec on the exact center of the fulcrums and vertical to the glueline. The bending resistance was calculated by reading the maximum force at the moment the text specimen broke.

2.3 Evaluation of the Data

The MSTAT-C package program was used in the statistical analysis of the data obtained with the measurements. The multiple analysis of variance was applied to the data obtained after the tests. The normality homogeneity of the values were provided prior to making the analysis of variance and the results that distorted the distribution of normality among the values were removed. When the difference among groups was significant at the end of the analysis of variance, a dual comparison was made with the Duncan test for the factors within the group. Subsequently, in the listings of success among each other of the factors taken as the average values, it was determined by separating the homogeneity groups according to the least significant difference (LSD) critical values.

3. Result and Discussion

The average values of the bending resistance obtained at the end of the bending tests in a direction parallel to the fibers are given in Table 2. The results of the multiple analysis of variance made for determining the variables, which are the cause of becoming different, are given in Table 3.

Table 2. The average values of bending resistance in a direction parallel to the fibers (N/mm^2)

Source				The Bending Resistance Values in a Parallel Direction to The Fibers	
Wood Species	**Cutting Direction**	**Joining Type**	**Adhesive Type**	$\bar{X}$ **(N/mm^2)**	**s**
Fir (G)	Tangential (T)	Flat Width (D)	Kleiberit 303 (K)	4,18	25,088
			Dorus MD073 (D)	3,67	22,008
		Triangular Strip of Wood (Ü)	Kleiberit 303 (K)	3,81	22,865
			Dorus MD073 (D)	3,63	21,782
		Serrated Width (K)	Kleiberit 303 (K)	3,72	22,330
			Dorus MD073 (D)	3,95	23,678
	Radial (R)	Flat Width (D)	Kleiberit 303 (K)	4,02	24,111
			Dorus MD073 (D)	4,72	28,336
		Triangular Strip of Wood (Ü)	Kleiberit 303 (K)	3,64	21,829
			Dorus MD073 (D)	3,43	20,598
		Serrated Width (K)	Kleiberit 303 (K)	4,62	27,746
			Dorus MD073 (D)	4,88	29,296

Beech (K)	Tangential (T)	Flat Width (D)	Kleiberit 303 (K)	8,44	50,609
			Dorus MD073 (D)	9,23	55,402
		Triangular Strip of Wood (Ü)	Kleiberit 303 (K)	7,57	45,397
			Dorus MD073 (D)	9,73	58,395
		Serrated Width (K)	Kleiberit 303 (K)	11,13	66,791
			Dorus MD073 (D)	13,14	78,838
	Radial (R)	Flat Width (D)	Kleiberit 303 (K)	13,50	81,009
			Dorus MD073 (D)	10,51	63,084
		Triangular Strip of Wood (Ü)	Kleiberit 303 (K)	7,06	42,386
			Dorus MD073 (D)	9,74	58,464
		Serrated Width (K)	Kleiberit 303 (K)	9,69	58,114
			Dorus MD073 (D)	16,39	98,366
Pine (Ç)	Tangential (T)	Flat Width (D)	Kleiberit 303 (K)	5,49	32,957
			Dorus MD073 (D)	4,72	28,325
		Triangular Strip of Wood (Ü)	Kleiberit 303 (K)	6,94	41,659
			Dorus MD073 (D)	3,74	22,454
		Serrated Width (K)	Kleiberit 303 (K)	3,59	21,534
			Dorus MD073 (D)	6,31	37,874
	Radial (R)	Flat Width (D)	Kleiberit 303 (K)	4,37	26,213
			Dorus MD073 (D)	6,30	37,794
		Triangular Strip of Wood (Ü)	Kleiberit 303 (K)	4,58	27,481
			Dorus MD073 (D)	4,55	27,301
		Serrated Width (K)	Kleiberit 303 (K)	6,97	41,788
			Dorus MD073 (D)	5,45	32,690

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

According to the results of the analysis of variance, the differences among the groups with a 5% error were found to be statistically significant for all the variables and the dual interactions and the wood species x cutting direction x joining type and the wood species x joining type x adhesive type trio interactions and the wood species x cutting direction x joining type x adhesive type quadruple interactions.

Table 3. The multiple analysis of variance related to bending resistance in a direction parallel to the fibers

Source	Sum of Squares	Degree of Freedom	Mean Square	F	P
Wood Species (A)	1710,916	2	855,458	1093,2080	0,0000
CuttingDirection (B)	21,800	1	21,800	27,8581	0,0000
Joining Type (C)	114,551	2	57,275	73,1934	0,0000
Adhesive Type (D)	19,427	1	19,427	24,8259	0,0000
A x B	11,360	2	5,680	7,2583	0,0009
A x C	94,250	4	23,563	30,1110	0,0000
B x C	29,677	2	14,838	18,9622	0,0000
C x D	35,829	2	17,915	22,8934	0,0000
A x D	45,671	2	22,836	29,1823	0,0000
B x D	3,064	1	3,064	3,9156	0,0494
A x B x C	22,729	4	5,682	7,2614	0,0000
A x B x D	0,041	2	0,021	0,0264	*NS*
A x C x D	75,932	4	18,983	24,2588	0,0000
B x C x D	3,763	2	1,882	2,4046	0,0932^{NS}
A x B x C x D	103,400	4	25,850	33,0342	0,0000
Error	140,854	180	0,783		
Total	2433,263	215			

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

The comparison results made to determine the smallest significant differences towards each other within the group of all the variables, which turned out to have a significant relationship with each other, are given in Table 4.

Table 4. The comparative results of the Duncan test related to bending resistance in a direction parallel to the fibers within the entire variables group (N/mm^2)

Wood Species	$\overline{X}$	*HG*	**Joining Type**	$\overline{X}$	*HG*
Fir (G)	4,02	C**	Flat Width (D)	6,60	B
Beech (K)	10,51	A*	Triangular Strip (Ü)	5,70	C**
Pine (Ç)	5,25	B	Serrated Width (K)	7,49	A*
LSD ± 0,291					
Cutting Direction	$\overline{X}$	*HG*	**Adhesive Type**	$\overline{X}$	*HG*
Tangential (T)	6,28	B**	Kleiberit 303 (K)	6,30	B**
Radial (R)	6,91	A*	Dorus MD073 (D)	6,90	A*
LSD ± 0,237					

HG : Group of Homogeneity *: The highest bending strength **: The lowest bending strength

The bending resistance in a direction parallel to the fibers among the wood species was the highest in Oriental beech at 10.51 N/mm^2 and the lowest in Uludağ fir at 4.02 N/mm^2. The bending resistance between the cutting directions was higher in the radial cut at 6.91 N/mm^2 and lower in the tangential cut at 6.28 N/mm^2. The bending resistance among the joining types was the highest in the serrated joinings at 7.49 N/mm^2 and the lowest in the triangular joinings at 5.70 N/mm^2. Furthermore, the bending resistance between the adhesive types was higher in the Dorus adhesives at 6.90 N/mm^2 and lower in the Kleiberit 303 adhesives at 6.30 N/mm^2.

According to the dual comparison results made to determine the smallest significant differences between the variables: Between the wood species-cutting direction, the higher interaction was in Oriental beech-radial at 11.15 N/mm^2 and the lower interactions were in the Uludağ fir-tangential at 3.83 N/mm^2 and in the Uludağ fir-radial at 4.22 N/mm^2. Between the wood species-joining type, the higher interaction was in Oriental beech-serrated at 12.59 N/mm^2 and the lower interaction was in Uludağ fir-triangle at 3.63 N/mm^2. Between the cutting direction-joining type, the higher interaction was in radial-serrated at 8.00 N/mm^2 and the lower interaction was in radial-triangle at 5.50 N/mm^2. Between the joining type-adhesive type, the higher interaction was in serrated-Dorus at 8.35 N/mm^2 and the lower interactions were in triangle-Kleiberit 303 at 5.60 N/mm^2 and in triangle-Dorus at 5.81 N/mm^2. Between the wood species-adhesive type, the higher interaction was in Oriental beech-Dorus at 11.46 N/mm^2) and the lower interactions were in Uludağ fir-Kleiberit 303 at 4.00 N/mm^2 and in Uludağ fir-Dorus at 4.05 N/mm^2. Between the cutting direction-adhesive type the higher interaction was in radial-Dorus at 7.33 N/mm^2 and the lower interaction was in tangential-Kleiberit 303 at 6.10 N/mm^2.

Table 5. The comparative results of the Duncan test for the wood species-cutting direction-joining type-adhesive type interaction (N/mm^2)

Source					
Wood Species	**Cutting Direction**	**Joining Type**	**Adhesive Type**	$\overline{X}$	*HG*
G	T	D	K	4,18	LMN
			D	3,67	LMN
		Ü	K	3,81	LMN
			D	3,63	MN
		K	K	3,72	LMN
			D	3,95	LMN
	R	D	K	4,02	LMN
			D	4,72	KLM
		Ü	K	3,64	MN
			D	3,43	N**
		K	K	4,62	KLMN
			D	4,88	KL
K	T	D	K	8,44	FG
			D	9,23	EF
		Ü	K	7,57	GH
			D	9,73	DE
		K	K	11,13	C
			D	13,14	B
	R	D	K	13,50	B
			D	10,51	CD
		Ü	K	7,06	HI
			D	9,74	DE
		K	K	9,69	DE
			D	16,39	A*

Ç	T	D	K	5,49	JK
			D	4,72	KLM
		Ü	K	6,94	HI
			D	3,74	LMN
		K	K	3,59	MN
			D	6,31	IJ
	R	D	K	4,37	KLMN
			D	6,30	IJ
		Ü	K	4,58	KLMN
			D	4,55	KLMN
		K	K	6,97	HI
			D	5,45	JK
LSD ± 1,007					

According to the trio comparison results made to determine the smallest significant differences among the variables: Among the wood species-cutting direction-joining type interaction, the highest interaction was in Oriental beech-radial-serrated at 13.04 N/mm^2 and the lowest interaction was in Uludağ fir-radial-triangle at 3.54 N/mm^2. In this situation, it can be stated that the radial surface and serrated joining displayed an influence of increase on the bending resistance. Among the wood species-joining type-adhesive type, the highest interaction was in the Oriental beech-serrated-Dorus at 14.77 N/mm^2 and the lowest interaction was in the Uludağ fir-triangle-Dorus at 3.53 N/mm^2.

Finally, among the wood species-cutting direction-joining type-adhesive type interaction, the quadruple comparison results made to determine the smallest significant differences are given in Table 5. The bending resistance in a direction parallel to the fibers was the highest in the Oriental beech-radial-serrated-Dorus interaction at 16.39 N/mm^2 and was the lowest in the Uludağ fir-radial-triangle-Dorus interaction at 3.43 N/mm^2. According to this, it can be stated that the wood species and joining type variables influence even more the bending resistance in a direction parallel to the fibers. The graph of the quadruple comparison results are given in Fig. 4.

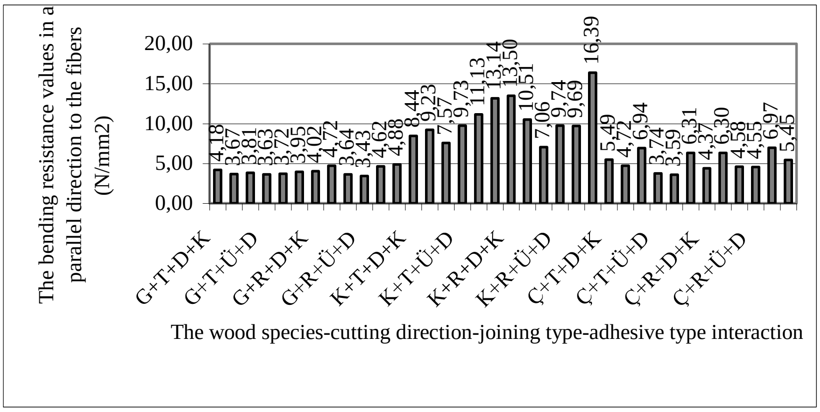


Figure 4. The bending resistance values in a parallel direction to the fibers for the wood species-cutting direction-joining type-adhesive type interaction

4. Conclusion

The bending resistance in a direction parallel to the fibers among wood species was the highest in Oriental beech at 10.51 N/mm^2 and the lowest in Uludağ fir at 4.02 N/mm^2. This situation could be expressed by the fact that the density of Oriental beech is high. Indeed, it has been stated in a study made that the differences in resistance among the wood species stem from the differences in the mechanical characteristics of the woods [16]. It was determined that between the cutting direction the higher bending resistance was in the radial cut at 6.91 N/mm^2 and the lower was in the tangential cut at 6.28 N/mm^2. This situation could stem from the fact that the forces were applied vertically to the fibers in a radial direction. It was stated in the literature that the modulus of elasticity in a radial direction of the wood materials is approximately two fold more compared to those in a tangential direction [10]. The bending resistance at the joining type level was the highest in the serrated joinings at 7.49 N/mm^2 and the lowest in the triangular joinings at 5.70 N/mm^2. This situation could be expressed by the fact that the bonding surface area in serrated joinings is greater. Furthermore, the bending resistance at the adhesive type level was higher in the Dorus adhesive at 6.90

N/mm^2 and lower in the Kleiberit 303 adhesive at 6.30 N/mm^2. This result could stem from the differences in the hardening of the adhesives. Indeed, in the studies made, the Dorus PVAc adhesive showed a better bending resistance than the Kleiberit 303 adhesive [17]. Furthermore, it was determined that in the joinings made with the Dorus adhesives to which a hardener has been added that the laminated wood materials showed a better resistance compared to the solid wood materials [18].

Between the wood species-joining type, the higher bending resistance was in Oriental beech-serrated at 12.59 N/mm^2 and lower in Uludağ fir-triangle at 3.63 N/mm^2. Between the cutting direction-joining type, the higher interaction was in radial-serrated at 8.00 N/mm^2 and lower interaction was in radial-triangle at 5.50 N/mm^2. This situation could be expressed by the fact that the bonding surface area in serrated joinings is greater. Indeed, in the studies made, it was determined that the resistances of the specimens made with a faultless serration structure and high-quality bonding were better [19,20]. Furthermore, it was observed that in case suitable adhesive is chosen, then solid panels to which wedge-shaped serrated joinings are applied showed the same resistance characteristics as the solid wood materials [21].

According to the results obtained, it could be proposed that Oriental beech wood-radial cutting direction-serrated width joinings-Dorus MD 073 adhesive be used in the production of EWPs that would be used in the desired applications for a high bending resistance in a direction parallel to the fibers. It was observed during the width joining application that the wood species was more influential than the cutting direction. The fact that the serrated joinings, as a joining type, produce better results shows that besides being used in length joinings, their application in width joinings as well would increase the resistance of the panels. Furthermore, it could be proposed to use it in places that are subjected to a high load.

The triangular cut width joining, which was produced for the first time within the scope of this study, could not display the expected performance. Nevertheless, there were no major differences between the triangular cut width joinings and the values of the flat width joinings, which are applied in the present productions. Furthermore, hardwood species, whose density is great, should be preferred in the EWP applications. A serrated width joining with a 5 mm serration depth should be used as a width joining application. Despite the fact that the PVA adhesives are in the D3 class as a characteristic, according to the results of the tests made, the use of the Dorus MD 073 adhesive could be proposed.

Acknowledgements

The authors wish to thank the Gazi University, Scientific Research Unit for the financial support (Project No. 07 / 2006 – 18).

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