IMPACTS OF DIFFERENT JOINT ANGLES AND ADHESIVES ON DIAGONAL TENSION PERFORMANCES OF BOX-TYPE FURNITURE

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The goal of this study was to determine the effects of different joint angles and adhesives on diagonal tension performances of the box-type furniture made from solid wood and medium density fiberboard (MDF). After drilling joints of 75º, 78º, 81º, 84º, and 87º degrees on Oriental beech, European oak, Scotch pine, and MDF samples, a diagonal tensile test was applied on corners glued with polyvinyl acetate (PVAc) and polyurethane (D-VTKA = Desmodur-Vinyl Trieketonol Acetate) according to ASTM D 1037 standard. With reference to the obtained results, the highest tensile strength was obtained in European oak with PVAc glue and joint angle of 84º, while the lowest value was obtained in MDF with D-VTKA glue and joint angle of 75º. Considering the interaction of wood, adhesive, and joint angle, the highest tensile strength was obtained in European oak with joint angle of 81º and D-VTKA glue (1.089 $N.mm^{-2}$), whereas the lowest tensile strength was determined in MDF with joint angle of 75º and PVAc glue (0.163 $N.mm^{-2}$). Therefore, PVAc as glue and 81º as joint angle could be suggested to obtain some advantageous on the dovetail joint process for box-type furniture made from both solid wood and MDF.

Keywords: Diagonal tensile strength; Joint angle; Dovetail; Corner joint; Adhesives; Wood materials

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INTRODUCTION

Furniture and composites are subjected to various forces directly or indirectly according to their usage. Compressive and tension forces are imposed on the joints of furniture. According to the impacts of these forces, deformations such as paring, bending, cracking, torsion failure, and rupture could be observed. In order to overcome these effects, improving the function of furniture and composites is vitally important for economy and usage (Atar 2006). Box-type furniture is one of the most important furniture types manufactured and used nowadays. It is used for storage in both houses and offices. The usage of box-type furniture goes back to 3000 years ago, and various regional impacts could play an important role in their creation (Ho and Eckelman 1994).

The construction style of furniture varies according to the type, value, quality of the furniture, occupational perception of the creator, packaging, and transportation. Each construction type has its own function and reasons for its preference. For corner joints of box-type furniture, dowel, biscuit, self-beaded, and various demountable joint types are applied (Wagner and Kicklighter 1996). Because of being a strong, industrial-grade joint, the dovetail joint is preferred in manufacture of mostly solid wood and medium density fiberboard (MDF) furniture. Its most important advantages are its lack of paring in the joint region and the fact that the plates are not arched. In case of gluing, the strength is increased (Rogowski 2002). Altinok (1998) reported that of the tensile strengths in a centre-legged table of beech and scotch pine dowel and dovetail joint, the highest tensile strength was found in dovetail joint of beech (2.27 $N.mm^{-2}$), and the lowest value was in scotch pine dowel with 0.96 $N.mm^{-2}$. Altinok (2006) found that the tensile strength of particleboard with Desmodur-Vinyl Trieketonol Acetate (D-VTKA) and table corner joint was obtained with beck glue in screw, dowel, screw + dowel, and plastic dowel construction, the highest value was found with D-VTKA + screw joint (9.674 $N.mm^{-2}$), and the lowest strength was obtained in Beck + plastic dowel joint with 1.672 $N.mm^{-2}$.

Ozciftci et al. (1996) determined that of the dowel, loose tongue, tongue, and groove corner joint applied from particle board and used in box-type furniture corners, the highest tensile strength was in the case of a dowel corner joint with 0.282 $N.mm^{-2}$, while the lowest value was in the case of a tongue and groove corner joint with 0.158 $N.mm^{-2}$. Safak (2000) stated that tensile strength in dowel + adhesive, tongue, and groove corner joint + glued, dowel + minifix, dowel + multifix corner joints obtained from particleboard and fiberboard, the highest strength was obtained in dowel + multifix corner joint for MDF with 3.730 $N.mm^{-2}$, while the lowest value was determined in tongue and groove corner joint with 0.201 $N.mm^{-2}$.

Atar et al. (2009) reported that the highest tensile strength in a wooden biscuit style joint used in box-type furniture joints was obtained in MDF + Desmodur-VTKA + miter joint with 2076 N, whereas the lowest strength was found in particleboard using polyvinyl acetate (PVAc) + butt joint with 453 $N.mm^{-2}$. In order to determine the effect of adhesive tension on some woods when PVAc glue is diluted in different rates, in the tension experiment using Oriental beech, European oak, and Scotch pine, the highest adhesive strength was obtained in Oriental beech + adhesive which is packing viscosity, the lowest as obtained in Scotch pine + 60 % diluted in solution (Atar 2007).

Gode (2005) studied tensile strength of corner joints applied on wooden drawer manufacture and obtained the highest strength value from screw joint parallel to mounting side and glued with PVAc in MDF, while the lowest value was observed from a joint parallel to the mounting side and glued with PVAc in MDF. Atar et al. (2008) studied the interaction of wood, adhesive, and joint angle. It was reported that the highest shear strength value was obtained in European oak with PVAc and joint angle of 78^{o} (339.2 kg.f), whereas the lowest value was determined in Oriental beech with PVAc and joint angle of 75^{o} (133 kg.f). Joint angle of dovetail joints in box-type furniture is 1:83 (83º) for softwood 1:6 (81º) for hardwood (Anonymous 2000). The objective of this study is to determine the effects of different joint angles and adhesives on diagonal tensile strength of the box-type furniture made from solid wood and MDF.

EXPERIMENTAL

Materials

Wood materials

Oriental beech (*Fagus orientalis* Lipsky), European oak (*Quercus petreae* Liebl.), and Scotch pine (*Pinus sylvestris* Lipsky) were used in this study as solid wood. Special emphasis was given for the selection of wood materials that were defect-free, proper, knotless, normally grown (without reaction wood, decay and mushroom damages according to TS 2470 (TS 2470 1976). The long wood materials were cut into smaller samples and then placed into a climate chamber. MDF specimens were obtained from whole size panels having 183 x 366 x 1.8 cm dimensions according to TS EN 326-1 (TS EN 326 1999).

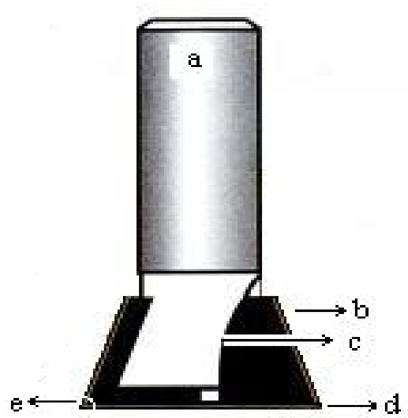
Adhesives

Polyvinyl acetate (PVAc) and polyurethane (D-VTKA = Desmodur-Vinyl Trieketonol Acetate) adhesives, which are commonly used in the wood industry and box-type furniture manufacture, were used in this study. The following adhesives were used in this experiment: PVAc is an odorless, nonflammable adhesive. It can be used in cold temperatures and solidifies quickly. Its application is very easy and does not damage the tools during the cutting process. However, PVAc adhesive's mechanical resistance decreases with increasing temperature. It loses bonding strength capacity over 70^{o}C. On the condition that the adhesive is applied to only one surface, using 150 to 200 g.m^{-2} adhesive seems to be suitable. The TS 3891 (1983) standard procedure was used to apply PVAc adhesive. The density of the PVAc adhesive was 1.1 g/cm^{3}, the viscosity was 16.000 ± 3.000 mPas, the pH value was 5, the solids content was 65 wt%, and the ash ratio was 3 %. A pressing time of 20 min for cold process and 2 min and 80^{o}C are recommended with 6 to 15 % humidity for the jointing process. After a hot-pressing process, the materials should be held until its normal temperature is reached (Ors 1987). PVAc adhesive was supplied by Polisan Inc., in Kocaeli, Turkey.

D-VTKA adhesive is widely preferred for assembly process in the furniture industry. It is a one component, polyurethane-based, and moisture-cured adhesive (Polisan 1997). The bonding surface should be clean, dry, dustless, and oil-free. Dry surfaces should be moistened so as to increase hardening speed of the glue. Glue is directly applied to one of the surfaces, and the bonding process is conducted at 20 ^{o}C and 65 % relative humidity conditions. Polyurethane glue has a pH of about 7 and a viscosity of 5500-7500 mPa s at 25 ^{o}C. Its density is 1.11±0,02 g/cm^{3}, and the period of solidification at 20^{o}C with 65 % relative humidity is 24 h. It is recommended that 150-200 g.m^{-2} of D-VTKA should be applied to both surfaces and held for about 6-10 min (Ors et al. 1999; Polisan 1997). PU adhesive was supplied by Polisan Inc. of Kocaeli, Turkey.

Dovetail joint cutter

Properties of the cutter produced in angles of 75º, 78º, 81º, 84º, and 87 º degrees and used in dovetail joint are given in Fig. 1.



a: Body, b: Cutter, c: Spiral, d: Cutting edge, e: Joint (cut) angle

Fig. 1. Dovetail joint cutter

Surface areas to be glued in dovetail joint according to cutter angles (A= joint and B: conjugate) are given in Table 1. According to this, the highest joint area is 75 degrees, and the lowest is 87 degrees.

Table 1. Joint Areas of A (joint) and B (conjugate) Composites in Dovetail Joint

Angle type	Area measured (mm^2)
75°	3684.1
78°	3567.72
81°	3462.03
84°	3364.64
87°	3275.93

Methods

Preparation of test samples

The most commonly used furniture combinations, comprised of Oriental beech, European oak, Scotch pine, 18 mm MDF, Poly(vinyl) acetate (PVAc), and Polyurethane (D-VTKA) as adhesives, (75º, 78º, 81º, 84º, 87º) degrees for joint angles, and the dovetail joint were used as the joining technique. According to this, 200 specimens are prepared from four material types (beech, oak, pine, MDF), 2 adhesive types, and 5 sample of each material (4 x 2 x 5 x 5). Each sample was composed of two composites of the same type, A and B. The composite specimens were prepared in 101.5 x 150 x 18 mm dimensions, where the measures of experimentation are given in Fig. 2.

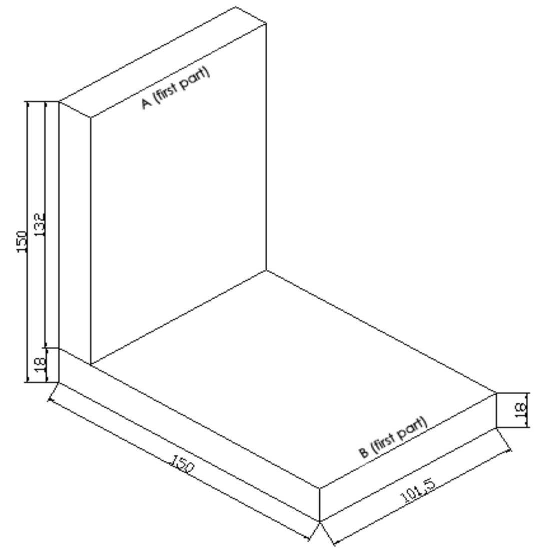


Fig. 2. Illustration of the experimental configuration (size in mm)

TSE 4951 (1986) was followed in preparation of experimental samples. Of the composites dovetail joined and prepared in 5 different angle (75º, 78º, 81º, 84º, 87º), joints were made on A and end-grain of a dovetail joint. Dimensions of dovetail joints are given in Fig. 3.

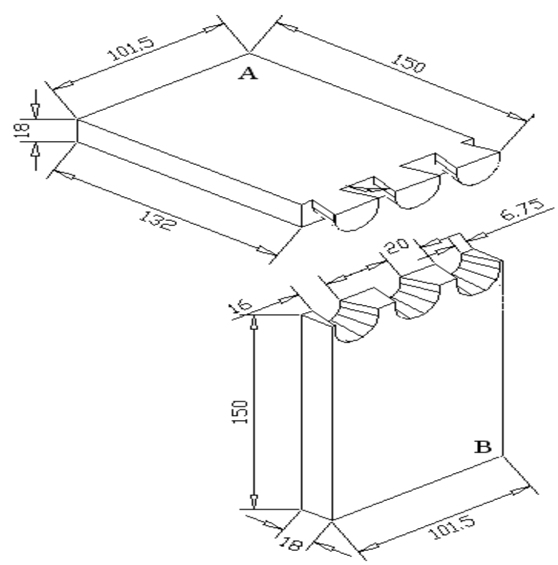


Fig. 3. Measures of dovetail joint (sizes in mm)

After adhesive application on joint surfaces of A and B-type composites, samples were mounted by pressure with a clamp. A pressure applied was equal to approximately 2-3 N.mm^{-2} (Demetci 1991). Samples were kept under a temperature of 20±2 °C and 65±5 % relative humidity until reaching to a constant weight.

Determination of diagonal tensile strength

A Zwick Z010 test machine of 10 kN (app. 1000 kg.) capacity (Quality Management Laboratories, Istikbal Furniture Inc. located in Kayseri, Turkey) was used for the experiments. The test was carried out according to ASTM D 1037 (1998). Diagonal tensile strength testing was carried out by applying the tool at a 0.15-0.25 mm/min loading speed. The forces of test samples in the event of deformation were measured in N (Newton) (Lesacher 1986).

The loading was continued until a break or separation occurred on the surface of the test samples, meanwhile, observing load (F_{max}). Taking into account the bonding surface area of the sample (A, in mm^2), the tensile strength (T) was calculated as follows:

$$T = \frac{F\max}{A} \quad N.mm^{-2} \tag{1}$$

The mechanism underlying the test is shown in Fig. 4.

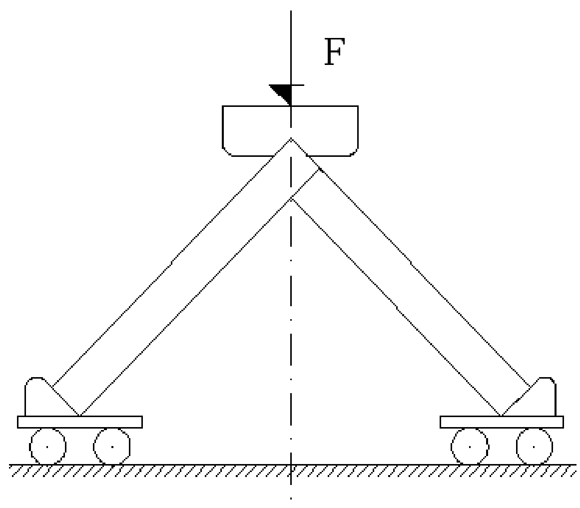


Fig. 4. Diagonal tension experiment

Statistical Analysis

In this study, to determine significance of main effects and interactions multiple variance analysis (MANOVA) was carried out. In order to determine the degree of importance when the interaction of factors are significant at 95% confidence, a Duncan test was applied.

RESULTS AND DISCUSSION

Values related to the effects of material, joint angle, and glue type of diagonal tensile strength on the dovetail joint are given in Table 2.

Table 2. Values Related to the effects of Material, Joint Angle, and Glue Type on the Tensile Strength ($N.mm^{-2}$)

Angle Type	Statistical Values	O+P	O+D	Ob+P	Ob+D	S+P	S+D	MDF+P	MDF+D
I (75°)	Max.	0.683	0.566	0.814	0.727	0.476	0.559	0.179	0.236
	Min.	0.657	0.523	0.747	0.519	0.373	0.529	0.154	0.193
	Sd	0.011	0.017	0.030	0.076	0.038	0.013	0.013	0.018
	v	0.009	0.016	0.027	0.068	0.034	0.012	0.011	0.016
	x	0.670	0.549	0.787	0.619	0.423	0.542	0.163	0.215
II (78 °)	Max.	0.787	0.763	0.913	0.673	0.656	0.689	0.183	0.188
	Min.	0.715	0.726	0.767	0.514	0.523	0.592	0.165	0.146
	Sd	0.033	0.014	0.053	0.061	0.062	0.035	0.007	0.018
	v	0.029	0.012	0.048	0.055	0.056	0.032	0.006	0.016
	x	0.752	0.744	0.844	0.571	0.589	0.635	0.171	0.171
III (81 °)	Max.	1.017	1.136	0.808	0.753	0.657	0.761	0.240	0.248
	Min.	1.013	1.040	0.784	0.698	0.609	0.727	0.182	0.244
	Sd	0.002	0.034	0.010	0.023	0.023	0.012	0.021	0.002
	v	0.001	0.037	0.009	0.021	0.021	0.011	0.019	0.001
	X	1.015	1.089	0.796	0.739	0.636	0.743	0.214	0.245
IV (84 °)	Max.	1.084	1.126	0.939	0.795	0.760	0.838	0.240	0.246
	Min.	1.054	1.071	0.857	0.730	0.657	0.782	0.203	0.226
	Sd	0.012	0.021	0.034	0.025	0.044	0.021	0.014	0.008
	v	0.010	0.019	0.016	0.022	0.039	0.018	0.012	0.007
	x	1.069	*1.096*	0.898	0.766	0.684	0.815	0.227	0.237
V (87 °)	Max.	0.919	0.786	1.111	0.608	0.790	0.815	0.277	0.294
	Min.	0.850	0.765	1.040	0.570	0.707	0.753	0.223	0.272
	Sd	0.030	0.008	0.026	0.016	0.030	0.022	0.022	0.009
	v	0.026	0.008	0.023	0.014	0.027	0.020	0.019	0.008
	x	0.884	0.779	1.073	0.587	0.756	0.786	0.262	0.284

Sd: Standard deviation, v: Variance, x: Average, O: European oak, Ob: Oriental beech, S: Scotch pine, MDF: Medium density fiberboard, I: 75º, II: 78º, III: 81º, IV: 84º, V: 87 º, P: Polyvinyl acetate glue, D: D-VTKA glue

The highest tensile strength was obtained from European oak glued with D-VTKA and jointed at an 84 degree angle (1.096 $N.mm^{-2}$), while the lowest was acquired in MDF glued with PVAc and jointed at 75 degrees (1.096 $N.mm^{-2}$). Multiple variance analysis of the effects of material type, joint angle, and glue type on diagonal tensile strength are given in Table 3.

Table 3. Multiple Variance Analysis Results of Diagonal Tensile Strength

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probably % 5 (Sig.)
A	3	145775682.020	48591894.007	4516.9644	0.0000
B	4	10449368.335	2612342.084	242.8359	0.0000
A x B	12	10202402.623	850200.219	79.0322	0.0000
C	1	712304.484	712304.484	66.2138	0.0000
A x C	3	7939791.687	2646597.229	246.0202	0.0000
B x C	4	1986924.899	496731.225	46.1747	0.0000
A x B x C	12	2128481.931	177373.494	16.4881	0.0000
Error	160	1721223.019	10757.644		
Total	199	180916178.997			

Factor A: Material type (Oriental beech, European oak, Scotch Pine, MDF)
Factor B: Joint Angle (75°, 78°, 81°, 84°, 87°)
Factor C: Adhesive type (PVAc, Desmodur-VTKA)

Differences between the effects of material and glue type and joint angle on diagonal tensile strength were statistically significant (α = 0.05). The Duncan test was carried out in order to determine these differences. Tensile strength averages according to material type are given in Table 4.

Table 4. Average Tensile Strength Values According to Material Type, Glue Type, and Joint Angle

Material type	x ($N.mm^{-2}$)	HG
*Wood material		
European oak (O)	0.861	A
Oriental beech (Ob)	0.767	B
Scotch pine (S)	0.658	C
Fiber Medium Board (MDF)	0.218	D
**Glue type		
PVAc (P)	0.644	A
D-VTKA (D)	0.609	B
***Joint angle		
75º (I)	0.496	E
78º (II)	0.560	D
81º (III)	0.685	B
84º (IV)	0.725	A
87º (V)	0.677	C

*LSD: 40.91, **LSD: 28.92, ***LSD: 45.73, x: Average, HG: Homogeneity groups

Tensile strength averages according to joint angles are given in Table 5.

Table 5. Tensile Strength Values According to Joint Angles

Process type	N.mm^{-2}	HG*
*Wood material + Angle type		
Ob+I	0.243	K
Ob+II	0.370	I
Ob+III	0.609	E
Ob+IV	0.297	J
Ob+V	0.694	D
O+I	0.823	A
O+II	0.823	B
O+III	0.615	E
O+IV	0.722	C
O+V	0.371	I
S+I	0.537	F
S+II	0.223	K
S+III	0.512	H
S+IV	0.624	E
S+V	0.577	G
MDF+I	0.625	D
MDF+II	0.684	C
MDF+III	0.699	C
MDF+IV	0.728	C
MDF+V	0.744	C
**Wood material + Glue type		
Ob+P	0.878	A
Ob+D	0.657	D
O+P	0.875	A
O+D	0.848	B
S+P	0.615	E
S+D	0.701	C
MDF+P	0.207	G
MDF+D	0.230	F
***Joint angle + Glue type		
I+P	0.511	E
I+D	0.481	F
II+P	0.589	C
II+D	0.530	E
III+P	0.665	B
III+D	0.705	A
IV+P	0.720	A
IV+D	0.728	A
V+P	0.744	A
V+D	0.609	D

* LSD = 91.47, ** LSD = 57.85, *** LSD = 64.68

The highest tensile strength according to material type was obtained in European oak (0.861 N.mm^{-2}), and the lowest was in MDF (0.218 N.mm^{-2}). Tensile strength averages according to material type declined in the order European oak, Oriental beech, Scotch pine, and MDF. The highest tensile strength according to glue type was obtained from PVAc (0.644 N.mm^{-2}), whereas the lowest value was in D-VTKA (0.609 N.mm^{-2}). According to joint angle, the strength value was determined to be the highest at 84 degrees (0.725 N.mm^{-2}); the lowest was at 75 degrees (0.496 N.mm^{-2}).

The highest tensile strength values according to wood material type and joint angle interaction were determined to be M + 75 degree (0.823 N.mm^{-2}), however the lowest was S + 78 degree (0.223 N.mm^{-2}). The highest tensile strength according to material and glue type interaction was reached with PVAc (0.878 N.mm^{-2}), and the lowest was in MDF + PVAc (0.207 N.mm^{-2}). The highest strength according to joint angle and glue type interaction was obtained in 84º + D-VTKA (0.728 N.mm^{-2}), and the lowest was determined in 75º + D-VTKA (0.481 N.mm^{-2}). Duncan test results for tensile strength are given in Table 6. It could be stated that after the tests the failure generally located within the wood, not within the glue. During the joint failure the surface regions of the wood materials had damage.

Table 6. Duncan Test Results of Tensile Strength

Process type	N.mm^{-2}	HG*	Process type	N.mm^{-2}	HG*
O+III+D	1.089	A	S+IV+P	0.684	H
O+IV+D	1.096	AB	Ob+I+D	0.619	H
O+IV+P	1.069	BC	S+II+D	0.635	H
Ob+V+P	1.073	C	S+III+P	0.636	HI
O+III+P	1.015	C	S+II+P	0.589	IJ
Ob+IV+P	0.898	D	Ob+II+D	0.571	JK
Ob+II+P	0.844	D	O+I+D	0.549	JK
Ob+I+P	0.787	D	S+I+D	0.542	JK
O+V+P	0.884	D	Ob+V+D	0.587	K
Ob+III+P	0.796	E	S+I+P	0.423	L
S+IV+D	0.815	E	MDF+V+D	0.284	M
O+II+P	0.752	EF	MDF+V+P	0.262	MN
O+II+D	0.744	EF	MDF+III+D	0.245	MN
Ob+IV+D	0.766	FG	MDF+IV+D	0.237	MN
S+V+D	0.786	FG	MDF+I+D	0.215	MN
S+III+D	0.743	FG	MDF+IV+P	0.227	N
Ob+III+D	0.739	FG	MDF+III+P	0.214	N
O+V+D	0.779	FG	MDF+II+D	0.171	O
S+V+P	0.756	G	MDF+II+P	0.171	O
O+I+P	0.670	G	MDF+I+P	0.163	O

*LSD = 0.09

The highest tensile strength according to material type, joint angle, and glue type was determined in M + III + D (1.089 $N.mm^{-2}$); however the lowest value was obtained in MDF + I + P (0.163 $N.mm^{-2}$).

CONCLUSIONS

1. The highest tensile strength according to material type was obtained from European oak, while the lowest was obtained from MDF. The tensile strength of European oak was 11% higher than oriental beech, 25% higher than Scotch pine, and 92% higher than those of MDF samples. The highest tensile strength according to joint angle was obtained from 84°, while the lowest was obtained from 75°. The tensile strength with a 84° joint angle was 3% higher than at a 81° angle, 9% higher than 87° angle, 19% higher than 78° angle, and 28% higher than 84° angle. This may be due to the parallel position between fiber and the fiber cut angle of the cutter prepared in 84° angle and the ductility of fiber when force is applied.

2. Regarding the adhesive type, the tensile strength of polyvinyl acetate was 5% higher than that of polyurethane (D-VTKA). Higher adhesion power of polyvinyl acetate might have influenced this result.

3. The highest tensile strength according to wood material type and joint angle interaction was obtained with O + 75°, while the lowest was in S+78°. This may result because of the high density of European oak and because outer surface area is greater than the others. The highest tensile strength according to material and glue type interaction was attained in Oriental beech + PVAc, and the lowest value was obtained in MDF + PVAc. This may be due by the homogeneity of Oriental beech, its high density, and the smoothness of its texture, which increases the adhesion of PVAc. The highest tensile strength according to joint angle and glue type interaction was reached with 84º + D-VTKA, while the lowest value was reached with 75º + D-VTKA. The results might be caused by the high adhesion power of the D-VTKA adhesive. The highest tensile strength according to material type, joint angle, and glue type was obtained from M+III+D, and the lowest was achieved from MDF + I + P.

4. Finally, in European oak furniture made of solid wood material which may be subjected to possible tension forces, 81º joint angle, D-VTKA adhesive, and dovetail joint construction may offer some advantageous. The findings obtained from this study could supply some valuable information regarding to advanced uses of the wood materials as bio-resource from forest.

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