THE EFFECTS OF EDGE BANDING THICKNESS OF ULUDAG FIR BONDED WITH SOME ADHESIVES ON WITHDRAWAL STRENGTHS OF BEECH DOWEL PINS IN COMPOSITE MATERIALS

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Composite materials and wooden dowels are being used increasingly in the construction of furniture frames and inner decoration. Yet there is little information available concerning the withdrawal strength of various fasteners, and, in particular, dowels in composite materials edged solid wood edge bandings. The aim of this study was to determine the withdrawal strengths of 6, 8, 10 mm diameter dowels produced from beech with respect to edge of a medium-density fiberboard (MDF) or particleboard (PB) edged with 5, 10 and 15 mm thickness of solid wood edge banding of uludag fir, bonded with different adhesives. According to TS 4539 standard, the effects of edge banding thickness, dimension of dowels, type of composite materials and type of adhesives used for edge banding on the withdrawal strength were determined. The highest (6.37 N/mm²) withdrawal strength was obtained in beech dowels with 8 mm diameter for MDF with 5 mm thickness of solid wood edge banding of uludag fir bonded with D-VTKA adhesive. According to results, if the hole wall and the surface of dowel are smooth then the adhesives give better mechanical adhesion with dowels and composite materials.

Keywords: Adhesives; Withdrawal strength of dowel; Wood composite; Wood edge bandings

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INTRODUCTION

Dowel joints are widely used in furniture frame construction, both as load-bearing structural connections and also as simple locators for parts. Joints constructed with dowels may be subjected to withdrawal, bending, shear, and tensional forces. The individual dowel pins used in the joints, however, are subjected to withdrawal and shear forces only (Eckelman and Erdil 1999).

Detailed knowledge of the holding strength of dowels in wood composites and laminated veneer lumber (LVL) is necessary for the rational design of furniture. The face withdrawal strength of plain dowels and spiral-grooved dowels in MDF, OSB (Oriented Strand Board), and PB was studied by Eckelman and Cassens. It was reported that plain dowels and spiral-grooved dowels with the fine grooving gave greater withdrawal strength from the face of particleboard than did multi-groove dowels, at least when an excess adhesive was applied in the holes and subsequently forced into the substrate as the dowels were inserted into the holes (Eckelman and Cassens 1985).

Englesson and Osterman found that applying glue to both the walls of the holes and the sides of the dowels (double gluing) resulted in a 35% increase in holding strength compared to coating the walls of the holes or sides of the dowels alone. They also found that filling the holes with adhesive so that the glue was forced into the porous surrounding substrate could appreciably increase joint strength (Englesson and Osterman 1972).

Bachmann and Hassler (1975) evaluated the withdrawal strength of dowels from both the faces and the edges of several types of particleboards. In general, they found that the withdrawal strength of dowels perpendicular to the face of the board was related to the internal bond strength of the board and the diameter of the dowel.

Zhang and Eckelman (1993) reported information on the strength of corner joints constructed with single dowels. The results showed that dowels should be embedded 2 or 2.5 cm thick butt members in order to obtain optimum bending strength.

According to Eckelman (1969,1979), the strength of joints can often be significantly improved through the proper use of an adhesive. Two factors are of interest. First, nominal levels of strength often can be significantly improved through the use of adequate adhesives and proper gluing techniques. Second, research has demonstrated the need to thoroughly cover the walls of dowel holes with adhesive to maximize the connection strength, and the strength of dowel joints can be significantly increased through the use of excess adhesives.

The aim of this study was to determine the connection resistance of dowels produced from beech wood and the effects of thickness, dimension of dowels, type of composite materials (MDF and particleboard) and type of adhesives used for edge banding on the withdrawal strength.

EXPERIMENTAL

Wood Materials

Beech wood (*Fagus orientalis lipsky*) was used for the production of dowels with 6, 8, 10 mm dimensions. Uludag fir (*Abies bornmülleriana Mattf.*) was used for edge banding with 5, 10, 15mm thickness. The density of the wood materials used in the study is shown in Table 1.

Table 1. Wood Materials Used as Raw Material

Wood Species	Density ($r_{12=}$ g/cm^3)	S.D.
Uludag fir (*Abies bornmülleriana Mattf.*)	0.434	0.0135
Beech (*Fagus orientalis lipsky*)	0.662	0.0188

$r_{12=}$Air dry density at 20^{o}C and 65 % relative humidity
S.D.=Standart Devision

Composite Materials

The following composite test panels were investigated:

- An MDF board, produced according to TS EN 622-3 standards, and with a density of 0.73g/cm^3 was purchased from a local merchant. Pieces measuring 100 x 100 x 18 mm were cut from the panel, which measured 2100 x 2800 x 18mm (TS EN 622-3 1999).

- A particleboard produced according to TS EN 312-1 standard with a density of 0.59 g/ cm^3 was purchased from a local merchant. Pieces measuring 100 x 100 x 18 mm were cut from the panel, which measured 2100 x 2800 x 18mm dimensions (TS EN 312-1, 1999).

Adhesives

Poly (vinyl acetate) (PVAc) adhesive is usually preferable for the assembly process in the furniture industry. According to the producer's recommendations, the adhesive was applied in the amount of 180-190 g/m^2 to the surfaces. Its viscosity was -16,000 ± 3000 mPa.s at 25 ^{o}C, density 1.1 ± 0,02 g/ml at 20 ^{o}C, and 20 minutes for cold process is recommended at 6-15 % humidity. The TS 3891(1983) standard procedure was used for applying PVAc adhesive, supplied by Polisan (a company in Izmit, Turkey).

The Producer firm describes Desmodur-VTKA as a polyurethane-based one-component solvent-free adhesive that is widely used for the assembly process in the furniture industry. It is used for gluing wood, metals, polyester, stone, glass, ceramic, PVC, and other plastic materials. Its application is specially recommended in locations subjected to high-level humidity. The gluing process was carried out at 20 ^{o}C and 65 % relative humidity. According to the producer's recommendations, the adhesive was applied in the amount of 180-190 g/m^2 to the surfaces. Its viscosity was -14 000 ± 3000 mPa.s at 25 ^{o}C, the density was 1.11 ± 0,02 g/ml at 20 ^{o}C, and it showed resistance against the cold air.

The producer firm describes Hot-Melt as based on thermoplastic synthetic resin that is used as an adhesive for the edge of melamine and polyester materials in the furniture industry. Its application is recommended in locations subjected to 8-10 % moisture. Temperature of adhesive gluing was carried out at 200-230 ^{o}C. The speed of the process of speed was 8-80 m/min.

Preparation of Test Samples

Wood materials were kept in a room at 20 ± 2°C and 65 ± 3 % relative humidity until their weight became stable. Then, 100 x 5 x 18 mm, 100 x 10 x 18 mm, and 100 x 15 x 18 mm pieces were cut from uludag fir sapwood, and each composite material was bonded with PVAc, D-VTKA and Hot-Melt adhesives. For dowels, 1000 x 11 x 11 mm pieces were cut from beech sapwood, and dowels having 6, 8 and 10 mm diameter were produced from these pieces using the dowel machines.

Dowel holes for withdrawal tests were drilled to 20 mm depth in the center of one edge of each specimen according to the procedure of TS 4539 standard (1983). All holes were drilled with standard twist drills. The diameter of the holes was 6, 8, and 10 mm. Before the dowels were inserted, PVAc adhesive (180 g/m^2) was applied both on their sides and on the hole surfaces. Before the withdrawal test, the samples were stabilized at 20 ± 2^{o}C and at 65 ± 3 % relative humidity to reach 12 % relative humidity at the end of the stabilization.

Determination of Density

The dry densities of the wood materials used for the preparation of treatment samples were determined according to TS 2472 (1976). Accordingly, air-dried samples were oven dried up to 103 ± 2°C until they reached constant weights. Then, the samples were cooled in a desiccator containing calcium chloride and weighed in an analytic balance with ± 0.01 g sensitivity. Afterward, the dimensions of the wood materials were measured by a compass with ± 0.001 mm sensitivity and the volumes were determined by the stereometric method. The ovendry density (δ_o) was calculated with the following equation:

$$\delta_o = M_o/\mathrm{V_o}\ (\mathrm{g/cm^3}) \qquad (1)$$

where M_o is the oven dry weight (g) and V_o is the dry volume (cm^3) of the wood material.

Test Method

All tests were carried out on a universal testing machine with a capacity of 4000 kPa equipped with jigs to hold the specimens as shown in Figure 1.

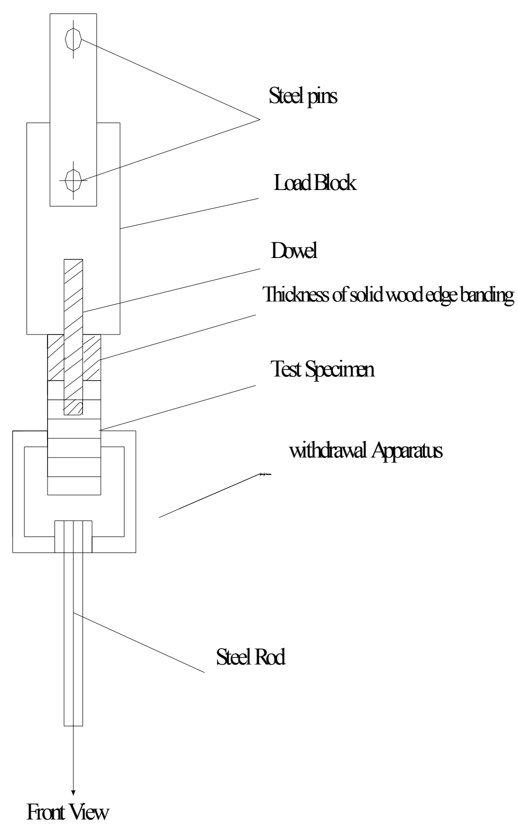

Figure 1. Apparatus used to hold specimens for testing withdrawal tests(Unver, 1992)

A loading rate of 5 mm per minute was used in all tests according to the ASTM 1037 standard (1988). The loading was continued until separation occurred on the surface of the test samples. Taking note of the observed load (F_{max}) and the bonding surface of sample (A), the withdrawal strength (σ_k) was calculated from equation 2:

$$\sigma_k = \frac{F\max}{A} = \frac{F\max}{h(2\pi r)} \qquad (2)$$

where σ_k is the withdrawal strength (N/mm^2), r is the radius of dowel (mm), and h is the depth of dowel embedded in the face member (mm).

Data Analyses

By using two different kinds of composite materials, three different diameters of dowels, three different thickness of solid wood edge banding, and three different types of adhesives as parameters, a total of 600 samples (2 x 3 x 3 x 3 x 10 + 60 control) were prepared, with ten samples for each parameter. Multiple variance analyses were used for determining the differences between the groups, and afterwards the Duncan test was executed to determine whether the differences had any significant levels.

RESULTS AND DISCUSSION

The average withdrawal strength values obtained from the test samples are given in Table 2, the average values of interactions between the factors are presented in Table 3, and the results of the multiple variance analyses connected with these values are shown in Table 4.

Table 2. Average Values of Withdrawal Strength (N/mm^2)

Factor Source		Withdrawal Strength (N/mm^2)
Composite Materials	Particleboard	3.810
	MDF	4.515
Thickness of solid wood edge bandings	5 mm	4.672
	10 mm	4.205
	15 mm	4.040
	Control	3.733
Diameter of Dowels(mm)	6	4.288
	8	4.328
	10	3.872
Types of Adhesives	Hot-Melt	3.967
	D-VTKA	4.303
	PVAc	4.218

The highest withdrawal strength value was obtained with MDF as the composite material, D-VTKA as the adhesive, 5 mm as thickness of solid wood edge banding, and 8 mm as dowel diameter.

Table 3. The Average Values of Interaction (N/mm^2)

Thickness of solid wood edge bandings	Adhesives	Composite Material	Diameter of dowels (mm)	Average Values(N/mm^2)	Standard Division
5 mm	Hot-Melt	Particleboard	6	4.203	0.1202
			8	3.062	0.0684
			10	4.195	0.1116
		MDF	6	4.576	0.1312
			8	5.970	0.1223
			10	4.605	0.1238
	D-VTKA	Particleboard	6	4.714	0.0816
			8	4.352	0.1268
			10	3.797	0.0386
		MDF	6	6.245	0.1548
			8	6.378	0.1794
			10	4.628	0.2092
	PVAc	Particleboard	6	4.113	0.0781
			8	4.367	0.1374
			10	3.354	0.1525
		MDF	6	4.288	0.1365
			8	4.180	0.1618
			10	5.457	0.0776
10 mm	Hot-Melt	Particleboard	6	4.600	0.0828
			8	3.653	0.1053
			10	3.101	0.0564
		MDF	6	4.103	0.1112
			8	4.676	0.1564
			10	4.076	0.1034
	D-VTKA	Particleboard	6	4.728	0.0632
			8	4.023	0.1021
			10	4.504	0.0666
		MDF	6	4.796	0.0955
			8	4.278	0.1195
			10	4.093	0.0960
	PVAc	Particleboard	6	4.703	0.2327
			8	3.762	0.0645
			10	3.394	0.0813
		MDF	6	4.257	0.1852
			8	4.736	0.1411
			10	4.209	0.2084
15 mm	Hot-Melt	Particleboard	6	2.964	0.1126
			8	3.848	0.0992
			10	3.290	0.0855
		MDF	6	3.727	0.1212
			8	3.354	0.0985
			10	3.982	0.0767

	D-VTKA	Particleboard	6	3.151	0.1147
			8	3.306	0.1414
			10	3.837	0.1222
		MDF	6	4.092	0.1292
			8	5.783	0.2214
			10	3.912	0.0782
	PVAc	Particleboard	6	4.096	0.0491
			8	4.671	0.0896
			10	3.415	0.1085
		MDF	6	4.437	0.0763
			8	4.568	0.0632
			10	4.980	0.0555
Control	Control	Particleboard	6	3.434	0.0810
			8	2.832	0.0923
			10	2.696	0.0805
		MDF	6	4.372	0.0950
			8	4.367	0.1328
			10	4.701	0.1468

According to the interaction of the average values obtained from the factors (type of adhesive, composite material, thickness of solid wood edge banding, dowel of diameter), 8 mm diameter of dowel and 5 mm thickness of solid wood edge banding gave the highest withdrawal strength value (6.37 N/mm^2) for the MDF with D-VTKA adhesive. Comparing particleboard with MDF, particleboard had poor results when determining withdrawal strength of dowel.

Table 4. Results of the Multiple Variance Analyses

Source of Variance	Sum of Squares	Degrees of freedom	Mean Square	F Value	P Sig.
Factor A	89.355	1	89.355	733.345	.000
Factor B	83.049	3	27.683	227.195	.000
Factor C	14.679	2	7.339	60.234	.000
Factor D	30.647	2	15.323	125.759	.000
A *B	62.487	3	20.829	170.946	.000
A * C	3.853	2	1.927	15.811	.000
B * C	30.893	6	5.149	42.256	.000
A * B * C	9.075	6	1.512	12.413	.000
A * D	13.317	2	6.659	54.648	.000
B * D	29.192	6	4.865	39.931	.000
A * B * D	31.804	6	5.301	43.503	.000
C* D	7.017	4	1.754	14.396	.000
A* C * D	5.258	4	1.314	10.788	.000
B* C * C	24.738	12	2.062	16.919	.000
A * B * C * D	25.469	12	2.122	17.419	.000

Factor A= Composite material (Particleboard, MDF),
Factor B = Thickness of solid wood edge banding,
Factor C = Type of Adhesives, Factor D = Diameter of Dowel,
F value = The F statistic is calculated by dividing the mean square by the mean square error.

The difference between the groups regarding to the effect of variance sources on withdrawal strength was meaningful (α =5 %). The results of the Duncan test conducted to determine the importance of the differences between the groups are given in Table 5.

Table 5. Results from the Duncan Test (N/mm^2)

Source of Variance	X	HG	Source of Variance	X	HG
K-P-3	2,69	a	I-T-P-1	4.20	klmno
K-P-2	2.83	ab	II-P-M-3	4.20	klmno
III-T-P-1	2.96	ab	II-V-M-2	4.23	klmnop
I-T-P-2	3.06	ab	II-P-M-1	4.25	klmnop
II-T-P-3	3.10	ab	I-P-M-1	4.28	lmnop
III-V-P-1	3.15	bc	I-V-P-2	4.35	lmnopr
III-T-P-3	3.29	cd	I-P-P-2	4.36	lmnopr
III-V-P-2	3.30	cd	K-M-2	4.36	lmnopr
I-P-P-3	3.35	cd	K-M-1	4.37	mnopr
III-T-M-2	3.35	cd	III-P-M-1	4.43	mnoprs
II-P-P-3	3.39	cde	II-V-P-3	4.50	noprs
III-P-P-3	3.41	def	III-P-M-2	4.56	oprs
K-T-1	3.43	def	I-T-M-1	4.57	oprs
II-T-P-2	3.65	efg	I-T-M-3	4.60	prs
III-T-M-1	3.72	efgh	II-T-P-1	4.60	prs
II-P-P-2	3.76	fgh	I-V-M-3	4.62	prs
I-V-P-3	3.79	fghı	III-P-P-2	4.67	prst
III-V-P-3	3.83	fghıj	II-T-M-2	4.67	prst
III-T-P-2	3.84	fghıj	II-P-P-1	4.70	prst
III-V-M-3	3.91	ghıjk	K-M-3	4.70	prst
III-T-M-3	3.98	hıjkl	I-V-P-1	4.71	prst
II-V-P-2	4.02	hıjklm	II-V-P-1	4.72	prst
II-T-M-3	4.07	ıjklmn	II-P-M-2	4.73	rstu
II-V-M-3	4.09	ıjklmn	II-V-M-1	4.79	stu
III-V-M-1	4.09	ıjklmn	III-P-M-3	4.98	tu
III-P-P-1	4.09	ıjklmn	I-P-M-3	5.45	u
II-T-M-1	4.10	ıjklmno	III-V-M-2	5.78	uv
I-P-P-1	4.11	ıjklmno	I-T-M-2	5.97	vy
I-P-M-2	4.18	jklmno	1-V-M-1	6.24	y
I-T-P-3	4.19	jklmno	1-V-M-1	6.37	z

Thickness of solid wood edge banding; I= 5 (mm), II= 10 (mm), III= 15 (mm), K= Control
Type of Adhesives; T= Hot-Melt, P= PVAc, V= D-VTKA
Composite Material; P= Particleboard, M= MDF
Diameter of Dowel; 1= 6 mm, 2= 8 mm, 3= 10 mm

Interactions between adhesive type and thickness of solid wood edge banding, diameter of dowel and composite material are given in Figs. 2, 3, and 4.

According to Fig. 2, composite materials for comparison, 5 mm and 10 mm in the highest withdrawal strength values was given D-VTKA. 15 mm in the highest withdrawal strength values was given PVAc.

According to Fig. 3, composite materials for comparison; withdrawal strength values of MDF withdrawal strength values of particleboard for % 25 more were found.

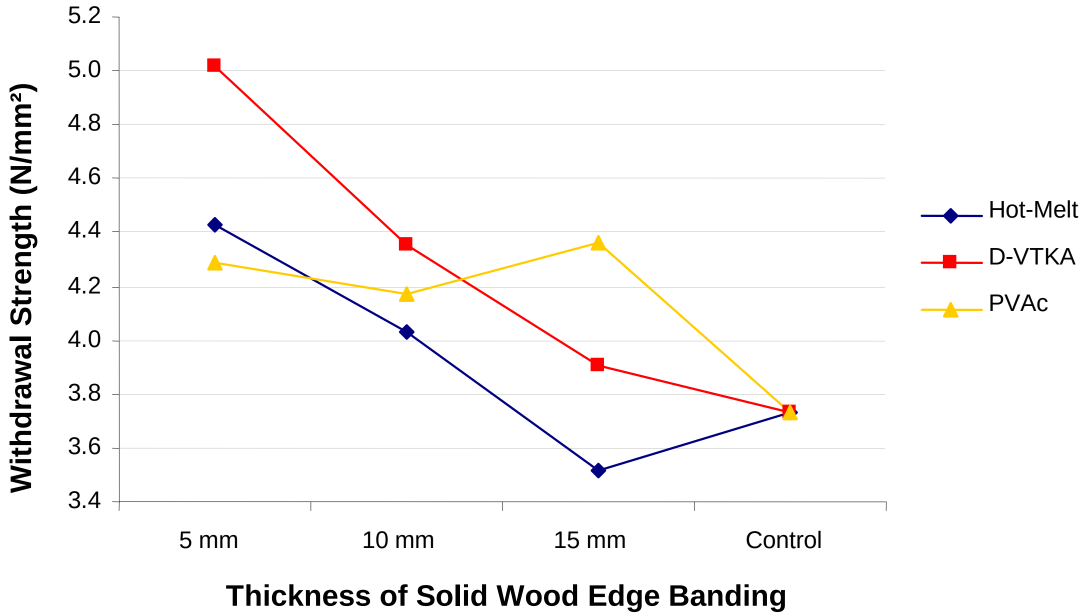

Figure 2. Effect of Types of Adhesives and Thickness of solid wood edge banding on withdrawal strength

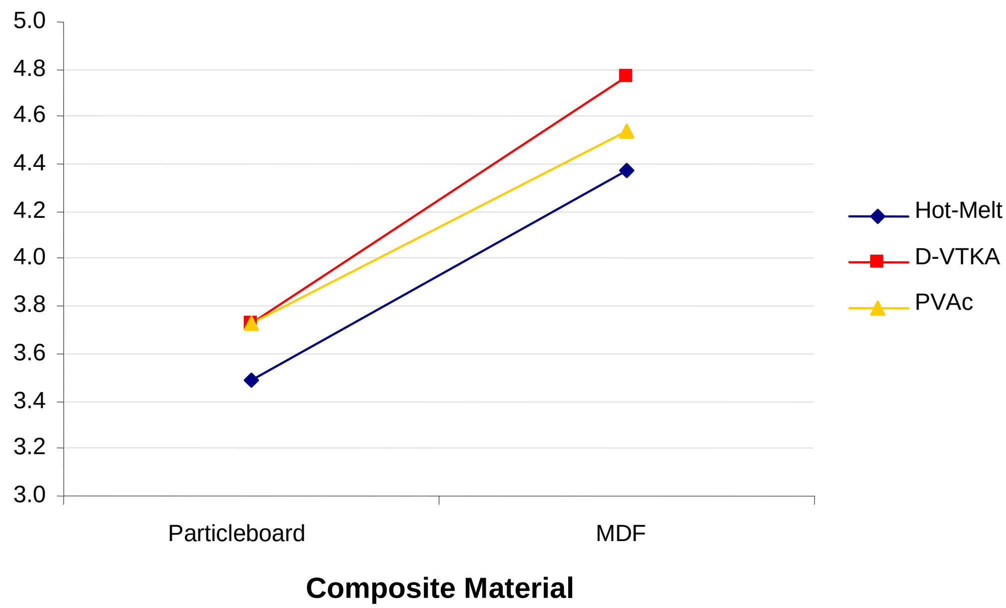

Figure 3. Effect of types of adhesives and composite materials on withdrawal strength

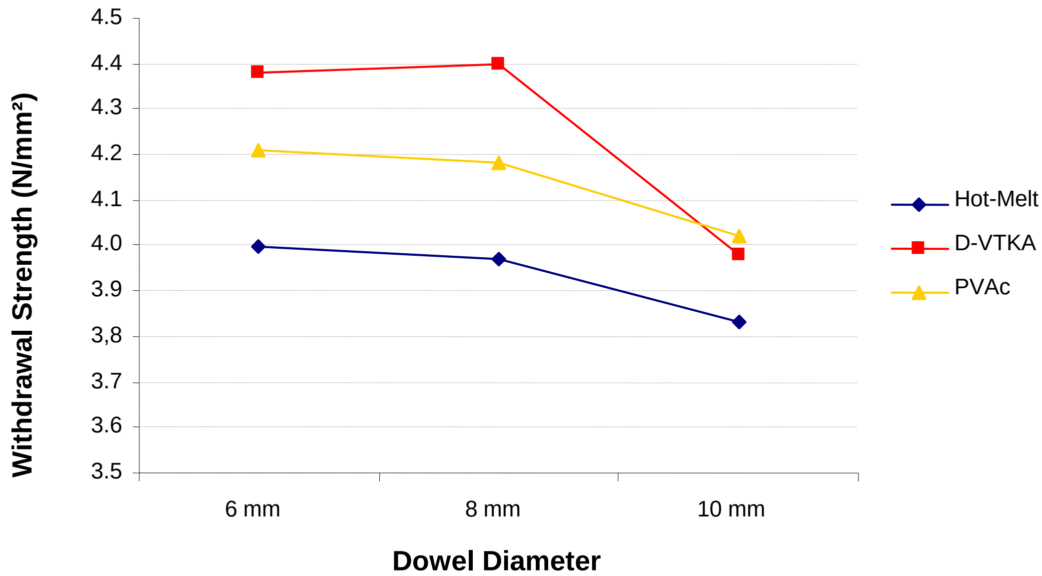

Figure 4. Effect of types of adhesives and diameter of dowels on withdrawal strength

With respect to composite material, Eckelman and Cassens (1985) showed that, in general, the holding strength of both MDF and particleboard could be predicted from the following theoretical expression:

$$F_2(\text{face}) = 15.5(IB)^{0.85}\, L^{0.85} \quad (3)$$

$$F_2(\text{edge}) = 15.5(IB)^{0.85}\, L^{0.85} \quad (4)$$

where, F_2 is the withdrawal strength (N/mm^2) of the dowel from face or edge, *IB* is the internal bond strength of the composite (N), and *L* is the depth of embedded dowel (mm).

The results of this study showed that there was a close linear relationship between predicted values and test results. However, this relationship did not hold for the adhesives tested in the same study. The highest withdrawal strength was obtained in MDF with 8 mm diameter of dowel and 5 mm thickness of solid wood edge banding D-VTKA adhesive, while the lowest withdrawal strength was obtained in particleboard with 10 mm diameter of dowel and without solid wood edge banding.

CONCLUSIONS

1. The withdrawal strength of dowels from the edges of MDF and particleboard is likely to be a function of mechanical properties of the base material, the process variables involved in the manufacture of the board, and the geometry of the particles or layers of the board. Better results were obtained with MDF than with particleboard because of the higher density and more homogeneous structure of MDF. This gives a smooth hole in the drilling process and smooth surfaces increase the bonding strength.

2. D-VTKA adhesive gave higher withdrawal strength values than PVAc and hot-melt adhesive. As D-VTKA cures, it swells and fills the gaps in the dowel holes, resulting in better mechanical adhesion. These results confirm earlier reports by Erdil and Eckelman, who stated that use of excess adhesives in the construction of joints largely outweighed the importance of the other factors and ensured construction of joints with maximum strength (Erdil and Eckelmann 2001).
3. As for the direction of withdrawal strength, the face direction was found to give higher strength values. The face direction of MDF gave the highest withdrawal strength. MDF has more homogeneous structure than particleboard that has three layers and a core layer consisting of large and heterogeneous flakes and chips. As a result, the dowel holes drilled are not smooth. Roughness of dowel holes reduces the mechanical adhesion between dowels and adhesives (Bachmann and Hassler 1975).
4. According to results, if the hole wall and the surface of dowel are smooth then the adhesives give better mechanical adhesion with dowels and composite materials. Moreover, if the dowels are subject to withdrawal strength, it is advised that beech dowel should be used on MDF with D-VTKA as the adhesive in furniture production and decoration application.

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Article submitted: June 23, 2009; Peer review completed: July 20, 2009; Revised version received: Sept. 17, 2009; Accepted: Oct. 8, 2009; Corrections to proof accepted: Oct. 26, 2009.