Effects of Dowels Produced from Various Materials on Withdrawal Strength in MDF and Pb

Burhanettin Uysal, Ayhan Özçifçi

Technical Programs, Safranbolu College, Zonguldak Karaelmas University, Karabük, Turkey

Received 17 January 2002; accepted 00 Month 2002

ABSTRACT: Wood dowels are commonly used in the construction furniture, but little information is available about the additive effects of dowels on the ultimate withdrawal strength of single or multidowel joints. This study was carried out to determine the tensile strength of 10-mm-diameter dowels produced from medium-density fiberboard (MDF), plywood, scotch pine (*Pinus sylvestris L.*), and beech (*Fagus orientalis lipsky*), bonded parallel and vertical to the surface of MDF and particleboard (Pb) with poly(vinyl acetate) (PVAc) and Desmodur-VTKA (D-VTKA). Tensile strength was applied to the dowels according to the procedure in the ASTM-D 1037 standard. The effects of dowel species, direction of tensile, composite material, and type of adhesive on tensile strength were determined. The results showed that the highest tensile strength was obtained in beech dowels bonded vertically with PVAc adhesive to the surface of MDF at 7.91 N/mm^2. If the dowels used in furniture production are subjected to great tensile strength, beech dowels bonded with PVAc adhesive on MDF should be used. However, when dowels produced from MDF and plywood waste are used, they also can produce positive results. © 2003 Wiley Periodicals, Inc. J Appl Polym Sci 88: 531–535, 2003

Key words: PVAc; Desmodur-VTKA; withdrawal strength of multigrooved dowel; MDF; particleboard

INTRODUCTION

One of the most noticeable trends of the past 35 years has been the steady increase in the use of wood–particle and wood–fiber composites in furniture. Also noticeable is the more recent rapid increase in the use of plywood composites as furniture frame stock. The increased use of composites previously could be attributed largely to supply-and-demand issues, although this product actually does have its own unique technical advantages. Consequently, replacement of solid wood by such composites has occurred largely in inexpensive furniture. However, as the world population continues to increase while the availability of solid wood regularly decreases, use of this material is necessarily accelerating as one of the few means of meeting world demands. As a result, these composites are used and promoted as such even in very high-quality furniture.[1]

It has been found that applying glue both to the walls of the holes and the sides of the dowels (double gluing) resulted in a 35% increase in holding strength compared with coating the walls of the holes or sides of the dowels alone. In addition, joint strength has been found to appreciably increased by filling the holes with adhesive so that the glue is forced into the surrounding porous substrate.[2]

Bachmann and Hassler[3] evaluated the withdrawal strength of dowels from both the face and edge of several types of particleboard. They found that in general 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 dowels.

Detailed knowledge of the holding strength of dowels in wood composites and laminated veneer lumber (LVL) is necessary for the rational design of furniture that employs test fasteners and materials in its construction. Little recent research has been carried out concerning the performance characteristics of dowels in these materials. An investigation was done of the face and withdrawal strength of plain dowels and spiral-grooved dowels on MDF, OSB, and Pb. It was found that plain dowels and spiral-grooved dowels with fine grooving showed greater withdrawal strength from the face of Pb than did multigroove dowels–at least when excess adhesive was applied in the holes and subsequently forced into the substrate as the dowels were inserted into the holes.[1]

Albin et al.[4] carried out extensive tests on corner joints constructed with adhesive and mechanical fasteners to determine their ultimate strength and to evaluate the proper method for testing such joints. They obtained significantly higher values with miter-type joints when the joints were loaded in compression as opposed to tension.

The investigation of Zhang and Eckelman[5] yielded pertinent information on the strength of corner joints

Correspondence to: B. Uysal (burhanettinuysal@hotmail.com).

Journal of Applied Polymer Science, Vol. 88, 531–535 (2003)

constructed with single dowels. Their results showed that dowels should be embedded in 1-inch- and three-quarter-inch-thick butt members in order to obtain optimum bending strength.

Dowels 6, 8, and 10 mm in diameter bonded with PVAc adhesive were tested according to the procedure in the ASTM-D 1037 standard[6] on waferboard (WFB) whose edges were drilled 25 mm in depth and that were covered with beech wood 5, 8 and 12 mm thick. The result of the face withdrawal strength test showed that the highest value (2.338 N/mm^2) was obtained in ϕ 6-mm dowel with the WFB that had 8-mm-thick beech wood, the lowest value (1.160 N/mm^2) in ϕ 10-mm-thick dowel with unprocessed WFB (Örs et al., 2000).

In the study Eckelman[7] carried out, it was found that often the strength of joints can be significantly improved through the proper use of adhesive. Two factors are of interest. Nominal levels of strength often can be significantly improved through the use of adequate adhesives and proper gluing techniques.

Research has amply demonstrated the need to thoroughly cover the walls of dowel holes with adhesive to realize the full strength of connection. In addition, research has also shown that the strength of dowel joints can be significantly increased through the use of excess adhesives[8,9]

The aim of this study was to determine whether the dowels produced from wastes of MDF and plywood can be used in the connection of furniture and also to determine the connection resistance of the dowels produced from different wood materials bonded with PVAc and D-VTKA adhesive on the edge and face of the MDF and Pb. In addition, this study can contribute to the knowledge in the furniture industry about the bonding strength of different dowel materials.

MATERIALS AND METHOD

Wood material

The following materials were used for producing multigrooved dowels:

- Plywood 4 mm thick in three pieces, produced according to the procedure in the TS 46 standard,[10] was bonded with PVA to make a 1000 × 1000 × 12 mm panel. Then the panel, whose density was 0.54 g/cm^3, was cut as 11 × 11 × 1000 mm pieces, and a ϕ10 mm dowel was produced in a dowel machine.
- MDF with a density of 0.73 g/cm^3 was produced according to the procedure in the TS EN 622-3 standard.[11] A piece 11 × 11 × 1000 mm in dimension was cut from panels, and then a ϕ10 mm dowel was produced in a dowel machine.
- Scotch pine (*Pinus sylvestris l.*) used was in accord with the TS 5005 standard.[12] Then 1000 × 11 × 11 mm pieces were cut from the sapwood of the materials, and dowels 10 mm in diameter were produced from these pieces with dowel machines.
- Beech (*Fagus orientalis lipsky*) in conformity with the TS 801 standard[13] was used. Then 1000 × 11 × 11 mm pieces were cut from the sapwood of the materials, and dowels 10 mm in diameter were produced from these pieces with the dowel machines.

The following composite test panels were used:

- MDF with a density of 0.73 g/cm^3 and produced according to the procedure in the TS EN 622-3 standard,[11] was purchased randomly from merchants and used. Pieces 100 × 100 × 18 mm in dimension were cut from the panel, which was 2100 × 2800 × 18 mm in dimension.
- Pb (particleboard) produced according to procedure in the TS EN 312-1 standards[14] was purchased randomly from merchants and used. Pieces 100 × 100 × 18 mm in dimension were cut from the panel, which was 2100 × 2800 × 18 mm in dimension.

Adhesive

The most commonly used adhesives in the furniture industry were chosen as bonding materials. PVAc with the following characteristics was used: density: 1.1 g/cm^3; viscosity: 16.000 ± 3.000 mPa/s; pH value and ash ratio: 5% and 3%, respectively. A pressing time of 20 min is recommended for a cold process and a time of 2 min at 80°C and 6%–15% humidity for the jointing process. After a hot-pressing process the materials should be held until normal temperature is reached. PVAc adhesive was supplied from Polisan (Izmit, Turkey), and the TS 3891 standard procedure[15] was used for applying adhesive, which was applied into the holes and surfaces of the dowels at 170–180 g/m^2.

Recently, Desmodur-VTKA adhesive usually has been found preferable for the assembly process in the furniture industry. It is a one-component solvent-free polyurethane-based adhesive used for gluing wood, metal, polyester, stone, glass, ceramic, PVC, and other plastic materials. It is especially recommended for application in locations subject to a high level of humidity.

TS 3891 standard procedure[15] was used for applying Desmodur-VTKA, supplied from a local producer (Ankara, Turkey).

Desmodur-VTKA adhesive can be applied as a cold. Its density is 1.1 g/cm^3, pH is approximately 7, and viscosity is 14,000 ± 3.000 mPa/s. At 20°C and 65%

relative humidity, it solidifies in 30 min. Because of its foaming character, polymarine adhesive can also be successfully used as a sealant or flexible filling agent. Being resistant to cold, it can be applied by hand. It is recommended that Desmodur-VTKA adhesive be applied to both surfaces 170–180 g/m^2, and adhesives should be held for about 30 min, according to its producer.

Preparation of test samples

Wood materials were held approximately 3 months in a room with a temperature of 20°C ± 2°C and a relative humidity 65% ± 3% . Then pieces 1000 × 11 × 11 mm were cut from sapwood of the materials, and dowels 10 mm in diameter were produced from these pieces with dowel machines.

Dowel holes for face withdrawal tests were drilled to 12 mm in depth in the center of each test block perpendicular to the face; similarly, holes for the edge withdrawal tests were drilled 18 mm in depth in the center of one edge of each specimen according to the TS 4539 standard. All holes were drilled with standard twist drills. Hole diameters were 10 mm. The walls of the holes and sides of the dowels were glued prior to insertion of the dowels. And adhesives were applied into the holes and surfaces of the dowels as 175 g/m^2.

Prepared samples were conditioned at 20°C ± 2°C and at 65% ± 3% relative humidity for at least 1 week before testing, and it was observed that they reached 12% relative humidity.

Test method

All tests were carried out on a universal testing machine that was equipped with jigs to hold the specimens, as shown in Figure 1. A rate of loading of 5 mm/min was used in all tests, according to the procedure in the ASTM 1037[6] standard.

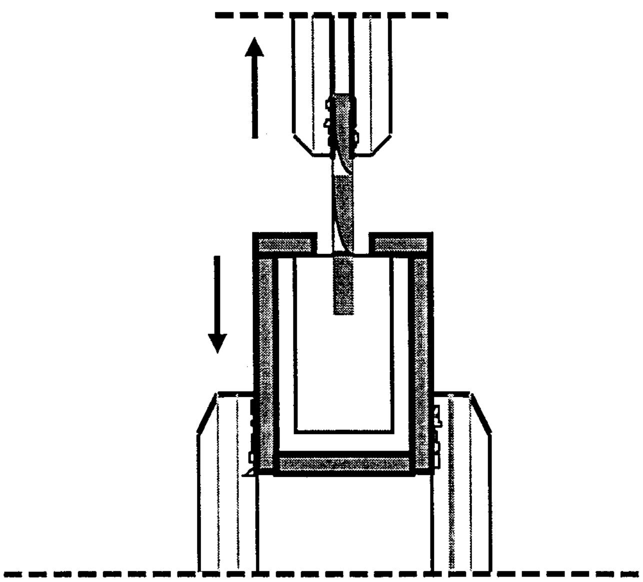

Figure 4 The test mechanism.

TABLE I
Average Values of Tensile Strength (σv; N/mm^2)

Source of factor		Tensile strength
Composite materials	MDF	4.60
	Pb	4.39
Type of adhesive	PVAc	5.31
	Desmodur-VTKA	3.68
Direction of tensile strength	Face of composite	5.05
	Edge of composite	3.95
Dowels species	MDF	3.99
	Plywood	4.68
	Pine	4.43
	Beech	4.89

The loading was continued until the separations occurred on the surface of the test samples; meanwhile, observing load (F_{max}), bonding surface of sample (A, N/mm^2), and withdrawal strength (σ_k) were calculated as follows:

$$\sigma_k = \frac{F\ \max}{A} = \frac{F\ \max}{h(2\pi r)} \tag{1}$$

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

Data analyses

By using two kinds of composite materials, two types of faces, four species of dowels, and two types of adhesives as parameters, a total of 320 samples (2 × 2 × 4 × 2 × 10) were prepared, with 10 samples for each parameter. Multiple variance analyses were done to determine the differences between the groups. Then the Duncan test was applied to determine if the differences were meaningful.

RESULT AND DISCUSSION

The average of calculated values obtained from the test samples according to the source of factor are given in Table I, the average values of interaction between the factors are given in Table II, and the results of the multiple variance analyses connected with these values are given in Table III.

According to the factors, the MDF composite material, the PVAc adhesive, face in the direction of tensile strength, and the beech dowel species were found to be most successful.

According to the interaction of the average values obtained from the factors (dowel species, type of ad-

TABLE II
Average Values of Interaction (N/mm²)

	Composite materials							
	Particleboard				MDF			
	PVAc		D-VTKA		PVAc		D-VTKA	
Types of Dowel	Face	Edge	Face	Edge	Face	Edge	Face	Edge
MDF	5.40	3.19	3.64	3.29	5.40	3.63	3.90	3.45
Plywood	5.27	4.49	4.12	3.72	7.17	3.92	4.23	3.51
Pine	5.80	5.05	3.66	3.38	6.49	4.04	3.60	3.46
Beech	5.35	6.86	4.13	3.74	7.91	3.99	3.67	3.47

hesive, composite material, direction of tensile strength), beech dowel provided the highest tensile strength value, at 7.91 N mm², on the face of the MDF with PVAc adhesive.

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

As the dowel produced from beech wood and bonded with PVAc adhesive gave the highest tensile strength on the face of MDF, the dowel produced from the MDF dowel bonded with PVAc gave the lowest tensile strength on the edge of Pb.

CONCLUSION

The test results showed that MDF, because its density is higher and its structure more homogenous, was more successful than Pb. So in the drilling process, smooth holes were available. Smooth surfaces increase bonding strength.[1]

The PVAc adhesive yielded higher values than the D-VTKA adhesive. PVAc is more elastic than D-VTKA adhesive, so it has greater mechanical adhesion with other elements. Englesson and Osterman[2] found that joint strength could be appreciably increased by filling the holes with adhesive so that glue was forced into the porous surrounding substrate.

The face direction was found more successful in the direction of tensile strength. In particular, MDF's face direction had the highest tensile strength. MDF is more homogeneous structure than Pb. Pb has three layers, and its core layer consists of large and heterogeneous flakes and chips, so dowel holes cannot be drilled smoothly. There cannot be mechanical adhesion between dowels and adhesives in rough holes. Bachmann and Hassler[3] 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 dowels.

Beech wood was found to be more successful than others. In the production of dowels, beech wood pro-

TABLE III
Result of Multiple Variance Analyses

Source of variance	Degrees of freedom	Sum of squares	Mean square	F value	Probability p
Factor A	1	12.215	12.215	118.9813	0.0000
Factor B	1	211.315	211.315	2058.3593	0.0000
A × B	1	9.330	9.330	90.8787	0.0000
Factor C	1	96.251	96.251	937.5515	0.0000
A × C	1	1.599	1.599	15.5749	0.0001
B × C	1	42.617	42.617	415.1240	0.0000
A × B × C	1	1.349	1.349	13.1341	0.0003
Factor D	3	35.989	11.996	116.8536	0.0000
A × D	3	24.470	8.157	79.4533	0.0000
B × D	3	21.785	7.269	70.7342	0.0000
A × B × D	3	9.893	3.298	32.1205	0.0000
C × D	3	7.189	2.396	23.3418	0.0000
A × C × D	3	3.540	1.180	11.4938	0.0000
B × C × D	3	2.860	0.953	9.2858	0.0000
A × B × C × D	3	7.540	2.513	24.4830	0.0000
Error	288	29.567	0.103		
Total	319	517.509			

Coefficient of variation = 7.12%, Factor A = composite material (MDF, Pb), Factor B = direction of tensile strength, Factor C = Type of adhesive, Factor D = dowel species.

TABLE IV
Result of Duncan Test (N/mm^2)

Source of variance	Average	HG	Source of variance	Average	HG
MDF, F, PVAc, MDF	5.40	F	Pb, F, PVAc, MDF	5.40	F
MDF, F, PVAc, Plywood	7.17	A	Pb, F, PVAc, Plywood	5.27	D
MDF, F, PVAc, Pine	6.49	C	Pb, F, PVAc, Pine	5.80	E
MDF, F, PVAc, Beech	7.91	A	Pb, F, PVAc, Beech	5.35	DE
MDF, F, D-VTKA, MDF	3.90	JKL	Pb, F, D-VTKA, MDF	3.64	LMN
MDF, F, D-VTKA, Plywood	4.23	HI	Pb, F, D-VTKA, Plywood	4.12	IJ
MDF, F, D-VTKA, Pine	3.60	L-O	Pb, F, D-VTKA, Pine	3.66	LMN
MDF, F, D-VTKA, Beech	3.67	LMN	Pb, F, D-VTKA, Beech	4.13	IJ
MDF, E, PVAc, MDF	3.63	LMN	Pb, E, PVAc, MDF	3.19	P
MDF, E, PVAc, Plywood	3.92	I-L	Pb, E, PVAc, Plywood	4.49	H
MDF, E, PVAc, Pine	4.04	IJK	Pb, E, PVAc, Pine	5.05	G
MDF, E, PVAc, Beech	3.99	IJK	Pb, E, PVAc, Beech	6.86	B
MDF, E, D-VTKA, MDF	3.45	M-P	Pb, E, D-VTKA, MDF	3.29	OP
MDF, E, D-VTKA, Plywood	3.51	M-P	Pb, E, D-VTKA, Plywood	3.72	KLM
MDF, E, D-VTKA, Pine	3.46	M-P	Pb, E, D-VTKA, Pine	3.38	NOP
MDF, E, D-VTKA, Beech	3.47	M-P	Pb, E, D-VTKA, Beech	3.74	KLM

F = face, E = Edge, Pb = Particle board, HG = Groups of homogeneous. LSD:0.282,

duces smoother surfaces because it has small trahee and a more homogeneous structure.

According to these results, if the surfaces of dowels and the walls of dowel holes are smooth, then adhesive can mechanically adhere to dowels and composite materials. If the dowels are subject to tensile strength, then it is advised that beech dowels be used on MDF with PVAc adhesive in furniture production and decorative applications. Although the tensile strength values of MDF dowels were lower than the others, it can be used in the construction of furniture, which is not subjected to force. And MDF dowels can be produced from remaining materials.

References

1. Eckelman, C.; Erdil, Z. Furniture Engineering and Quality of Life; 1st International Furniture Congress Proceedings, Istanbul, 1999, 306.
2. Englesson, T., Osterman, A. Assembly of Chipboard with Round Dowels; Swedish Forest Products Research Laboratory, Report 28, Stockholm, 1972.
3. Bachmann, G.; Hassler, W. Holztecnologie 1975, 16(4), 210.
4. Albin, R.; Müller, M.; Scholze, H. Holz als Roh-Und Werkstoff 1987, 45(5), 171.
5. Zhang, J. L.; Eckelman, C. A. Forest Product J 1991, 43(11), 19.
6. ASTM D 1037. Standard Methods of Evaluating the Wood-Base Fiber and Particle Materials; American Society for Testing and Materials: Philadelphia, 1988.
7. Eckelman, C. A. Forest Product J 1979, 29(1), 48.
8. Eckelman, C. A. Forest Products J 1969, 19(12), 52.
9. Eckelman, C. A.; Cassens, D. L. Forest Products J 1985, 35(5), 55.
10. TS 46. Plywood—Veneer Plywood with Rotary Cut Veneer for General Use; Inst. of Turkish Standard, 1986.
11. TS EN 622-3. Fibre Boards—Properties of Medium Density Fibre Boards; Inst. of Turkish Standard, 1999.
12. TS 5005. Timber of Scotch Pine (for General Use); Inst. of Turkish Standard (1987).
13. TS 801. Timber—Beech (for General Use); Inst. of Turkish Standard, 1991.
14. TS EN 312-1. Particle Boards—For General Use; Inst. of Turkish Standard (1999).
15. TS 3891. Adhesives, Polyvinyl Acetate Emulsion; Inst. of Turkish Standard, 1983.
16. Örs, Y.; Özçifçi, A. J Inst Sci Tech 2000, 13(1), 15.
17. Producer Firm Text. Polisan Dilovası-Gebze, Bolu, Turkey, 1999.