WITHDRAWAL STRENGTH OF VARIOUS LAMINATED VENEER DOWELS FROM COMPOSITE MATERIALS

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ABSTRACT

Dowel withdrawal strength is a critical component of wood connection design. Previous tests have concentrated on defining the relationship between dowel-bearing strength, specific gravity, and fastener characteristics such as diameter; but little information is available about the additive effects of laminated veneer dowels on the ultimate withdrawal strength of single- or multi-dowel joints. In this study, we researched the effect withdrawal strength of various laminated veneer dowels from various woods produced on the composite materials. Five wood species for outer layer, three wood species for inner layer, and PVAc adhesive were used in the production of multi-grooved dowels. Withdrawal strength tests were applied according to ASTM-D 1037 standards. The test results indicated that the highest strength was obtained in beech dowels having poplar wood for the inner layer on face withdrawal strength in medium density fiberboard (MDF) as 7.47 N/mm^2. The lowest strength was obtained in oak dowels having pine wood for the inner layer on edge withdrawal strength in particleboard as 2.82 N/mm^2. If the dowels used in furniture production are subject to great withdrawal strength, laminated beech veneer dowels bonded with polyvinyl acetate (PVAc) adhesive on MDF should be used. In addition, when the dowels produced from waste wood are used, they also give the same results as the solid dowels.

Keywords: Dowels, MDF, Particleboard, PVAc, withdrawal strength.

INTRODUCTION

Detailed knowledge about 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. The face withdrawal strength of plain dowels and spiral-grooved dowels on medium density fiberboard, oriented strandboard, and particleboard was researched. It is recommended that plain dowels and spiral-grooved dowels with fine grooving give greater withdrawal strength from the face of particleboard than the multi-grooved dowels—at least when excess adhesive is applied in the holes and subsequently forced into the substrata as the dowels are inserted into the holes (Eckelman and Cassens 1985).

It was found that applying adhesive 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 (Englesson and Osterman 1972). It was also found that joint strength could be appreciably increased by filling the holes with adhesive so that the glue is forced into the porous surrounding substrata.

Bachmann and Hassler (1975) evaluated the withdrawal strength of dowels from both the face and edge of several types of particleboard. In general, they found that the withdrawal strength of dowels perpendicular to the face of the board is related to the internal bond strength of the board and the diameter of the dowels.

Zhang (1991) yielded pertinent information on the strength of corner joints constructed with the single dowels. The result showed that dowels should be embedded in 1.75-in.-1-in. thick butt members in order to obtain optimum bending strength.

Dowels, having 6-, 8-, and 10-mm diameters bonded with PVAc adhesive were tested according to ASTM-D 1037 standard on waferboard (WFB), whose edges were stuck together with beech wood having 5-, 8-, and 12-mm thickness, drilled 25 mm in depth. In the results of the withdrawal strength of the edge of WFB test, the highest value (2.338 N/mm^2) was obtained in ∅ 6-mm dowels with WFB, whose edges were stuck together with beech wood of 8-mm thickness; the lowest value was (1.160 N/mm^2) in ∅10-mm dowel with plain WFB (Örs and Özçifçi 2000).

This test was performed to determine the resistance of connections between the board types used in industry and the dowels made from various wood materials bonded with adhesives containing Desmodur-VTKA and polyvinyl acetate (PVAc). The tensile resistance of Scotch pine (*Pinus silvestris L*), oriental beech (*Fagus orientalis lipsky*), and oak (*Quercus petraea* spp.) using cross and radial sections with Desmodur-VTKA adhesive was made in the edges of Pbd and MDF, both plain and stuck together beech wood with polyvinyl acetate (PVAc) adhesive. The results of the experiments showed that the highest tensile resistance was obtained by a cross section of the beech wood as (4.403 N/mm^2) and in the edges of MDF stuck together with beech as (5.818 N/mm^2) (Örs and Özçifçi 1999).

A study was performed to determine the effects of the diameter of the dowel, the number of layers of laminated veneer lumber (LVL), and the types of adhesives on the withdrawal strength of dowels. For this purpose, LVL was manufactured from 4-, 5-, and 7-mm thick pine and beech with polyvinyl acetate (PVAc) and Desmodur-VTKA. The withdrawal strength of beech dowels in 8- and 10-mm diameters was applied to LVL according to ASTM-D 1037 standard. The highest withdrawal strength was obtained in the beech dowels of 10 mm diameter (7,271 N/mm^2) in the LVL manufactured from the 5-mm thick beech wood bonded with Desmodur-VTKA adhesive (Özen and Uysal 2000).

Objectives

The work reported in this paper was carried out to determine the withdrawal strength of laminated veneer dowels, produced from various wood species and bonded with PVAc adhesive on Pbd and MDF. The results also give information to the furniture market on the withdrawal strength of laminated veneer dowel materials.

METHODOLOGY

Wood materials

The following wood species were used for laminated veneer dowels: beech (*Fagus orientalis lipsky*), white mulberry (*Morus alba L.*), oak (*Quercus petraea* spp.), mahogany (*Khaya A. Juss.*), and walnut (*Juglans regia L.*) for outer layers; poplar (*Populus nigra*), Uludag fir (*Abies bornmülleriana mattf.*), and Scotch pine (*Pinus silvestris L*) for inner layers. These wood materials were chosen randomly from the timber merchants of Ankara, Turkey. Special emphasis was given to the selection of the wood materials. Accordingly, nondeficient, knotless, normally grown wood materials (without zone line, reaction wood, decay, and insect mushroom damage) were selected.

The following composite test panels were used:

MDF with a density of 0.73 g/cm^3, produced according to the procedure in the TS EN 622-3 standard, was purchased randomly from merchants. Particleboard produced according to procedure in the TS EN 312-1 standard was also purchased randomly from merchants.

Adhesive

Polyvinal acetate with of the following characteristics was used. The density of PVAc was 1.1 g/cm^3, and the viscosity was 16.000 ± 3.000 mPa s; pH value and the ash ratio were 5 and 3% respectively. PVAc adhesive was supplied from Polisan, a producer firm in Izmit, Turkey, and TS 3891 standard procedure was used to apply adhesive. The adhesive applied into the holes and surfaces of the dowels as 170–180 g/m^2.

Sample preparation

The samples of the Pbd and MDF were prepared as in Fig. 1a and 1b. The pieces of samples with the dimensions 100 × 100 × 18 mm were cut from the panel with the dimensions 2100 × 2800 ×

18mm. Laminated veneer blocks were prepared from 3.5-mm veneers of various wood species, and PVAc adhesive was applied to the surface of veneers as 170–180 g/m². Laminated veneer blocks were kept approximately 3 months in a room with a temperature of 20°C ± 2°C and a relative humidity 65% ± 3%. Then the pieces with the dimensions 1000 × 11 × 11 mm were cut from the laminated veneer blocks; and the dowels 10 mm in diameter were produced from these pieces with the dowel machines. The cross section of the multigrooved-veneer dowels is shown in Fig. 2.

Dowel holes for face withdrawal tests were drilled at 12-mm depth in the center of each test block perpendicular to the face; similarly, holes for the edge withdrawal tests were drilled at 18 mm in the center of one edge of each sample according to the procedure of TS 4539 standards. All holes were drilled with standard twist drills. The diameter of the holes was 10 mm. The walls of the holes and the sides of the dowels were coated with adhesive prior to insertion of the dowels. All samples had been conditioned at 20 ± 2°C and at 65 ± 3 % relative humidity at least 1 week before the test was done.

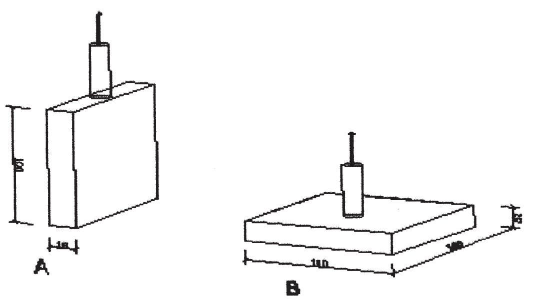

FIG. 1. Dowel connection in composite material.

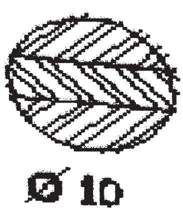

FIG. 2. Cross section of dowel.

Withdrawal strength test

All tests were carried out on a universal testing machine, which was equipped with jigs to hold the specimens, as shown in Fig. 3 and Fig. 4. A rate of loading of 5 mm per minute was used in all tests according to ASTM 1037 standards. The loading was kept on until the separation occurred on the surface of the test samples; meanwhile, the load (F_{max}), the bonding surface of the sample (A, N/mm²), and the withdrawal strength (σ_k) were calculated as follows;

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

where

F_{max} = maximum force (N)
A = square meter (mm²)
σ_k = withdrawal strength resistance (N/mm²)
r = semi diameter of dowel (mm)
h = depth of dowel embedment in the face member (mm)

Data analyses

By using two different kinds of composite materials (MDF and Pbd), two different withdrawal strength directions (edge and face), five different types of dowels (beech, white mulberry, oak, mahogany, and walnut), and three different types of inner layer (poplar, Uludag fir, and pine) as parameters, a total of 600 samples (2 × 2 × 5 × 3 × 10) were prepared, with ten samples for each parameter. Multiple variance analysis (MANOVA) was used to determine the differences between the withdrawal strengths of the dowels. It was determined by the Duncan test that there was a significant difference between the groups.

RESULTS AND DISCUSSION

Calculated densities of laminated veneer dowels are given in Table 1. The highest density was obtained in the oak dowel having Uludag fir for the inner layer as 0.78 g/cm^3. High density of the oak wood, adhesive, and pressure applied in the producing of the dowel can cause this high density.

According to the face and edge withdrawal strength test, average values of the withdrawal strength tests are given in Table 2.

TABLE 1. *Density of laminated veneer dowels.*

Outer Layer	Inner Layer	Density (g/cm^3)
Walnut	Uludag fir	0.64
	Scotch pine	0.66
	Poplar	0.60
Beech	Uludag fir	0.57
	Scotch pine	0.65
	Poplar	0.54
Oak	Uludag fir	0.78
	Scotch pine	0.75
	Poplar	0.74
White mulberry	Uludag fir	0.55
	Scotch pine	0.59
	Poplar	0.53
Mahogany	Uludag fir	0.67
	Scotch pine	0.67
	Poplar	0.60

TABLE 2. *Average results of the face and edge withdrawal strength test.*

Types of material	Average withdrawal strength value (N/mm^2)
Composite materials	
Pbd	3.78
MDF	4.93
Direction of withdrawal strength	
face	4.65
edge	4.07
Laminated veneer dowels	
beech	4.46
white mulberry	4.34
oak	4.40
mahogany	4.20
walnut	4.35
Inner layer material of dowel	
poplar	4.41
Uludag fir	4.40
scotch pine	4.20

Between the MDF and Pbd, the highest value of withdrawal strength was for MDF. This may be because MDF has the higher density and its structure is homogenous. So it may be attributed to the increase in the internal bond for adhesive. It was observed that the highest withdrawal strength was obtained on the faces of composites. Among the laminated veneer dowels, the highest value of withdrawal strength was obtained in laminated beech veneer dowels. Beech veneer has a higher withdrawal strength due to its higher density and its homogenous structure.

Multiple variance analysis was performed to determine the differences between the withdrawal strengths of the laminated veneer dowels. The result of multiple variance analysis is given in Table 3.

The difference between the groups related to the effect of variance sources on withdrawal strength was significant ($\alpha = 5$ %). DUNCAN tests were conducted to determine the importance of the differences between the groups given in Table 4. According to the Duncan test results, laminated beech veneer dowels with poplar veneer for the inner layer gave the highest value on the face of MDF.

CONCLUSIONS

Results of the study indicated that laminated beech veneer dowels with poplar veneer for the inner layer gave greater withdrawal strength from the face of MDF than the face of Pbd when excess adhesive was applied to the holes and subsequently forced into the substrata as the dowels were inserted into the holes. Owing to the large flakes and chips in its inner layer, Pbd had the lower edge withdrawal strength. Similarly, the edge withdrawal strength of MDF was lower than the face withdrawal strength because the flakes were parallel to the longitudinal of MDF. Finally, a surface effect on thicker boards would presumably have greater holding strength than a thin surface. On the whole, holding strength in both MDF and Pbd could be predicted according to:

$$\sigma_{k\,(face)} = F_2/A = F_2/\pi DL \text{ N/mm}^2 \qquad (2)$$

TABLE 3. *The result of multiple variance analyses of composite material species, types of face, wood species and types of layer.*

Source	Degrees of freedom	Sum of square	Means of square	F value	Probability α= α5 %
Int.-A	1	199.386	199.386	821.0244	0.0000
Int.-B	1	49.582	49.582	204.1680	0.0000
AB	1	11.654	11.654	47.9878	0.0000
Int -C	4	3.928	1.223	5.0367	0.0005
AC	4	4.893	0.982	4.0437	0.0031
BC	4	16.146	4.036	16.6210	0.0000
ABC	4	14.051	3.513	14.4650	0.0000
Int-D	2	7.728	3.864	15.9105	0.0000
AD	2	8.965	4.482	18.4575	0.0000
BD	2	18.605	9.303	38.3057	0.0000
ABD	2	4.828	2.414	9.9405	0.0001
CD	8	36.243	4.530	18.6851	0.0000
ACD	8	10.765	1.346	5.5412	0.0000
BCD	8	49.364	6.170	254085	0.0000
ABCD	8	28.609	3.576	14.7254	0.0000
Error	540	131.139	0.243		
Total	599	595.885			

Int.-A= Composite Material, Int.-B= Withdrawal strength, Int.-C= Wood Materials, Int.-D= Inner layer.
Coefficient of variation: 11.30%.

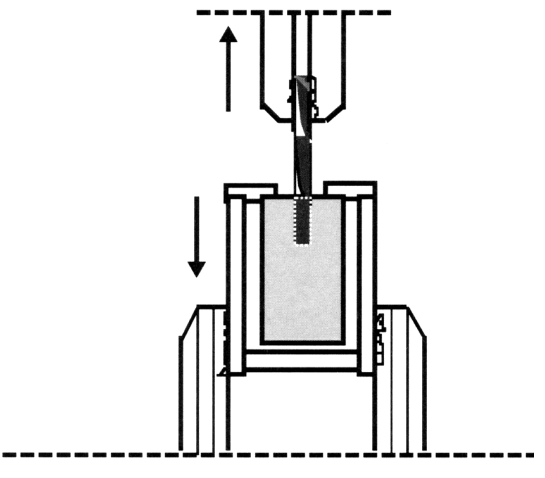

FIG. 3. Edge withdrawal test.

$$\sigma_{k(edge)} = F_3/A = F_3/\pi DL \text{ N/mm}^2 \qquad (3)$$

where;

$\sigma_{k\,(face)}$ = internal bond (3.52)
$\sigma_{k\,(edge)}$ = internal bond (4.24)
F_2 = withdrawal strength of the dowel from the face of the board (N/mm^2)
D = diameter of the dowel (10 mm)
L = depth of the embedment of the dowel (mm)

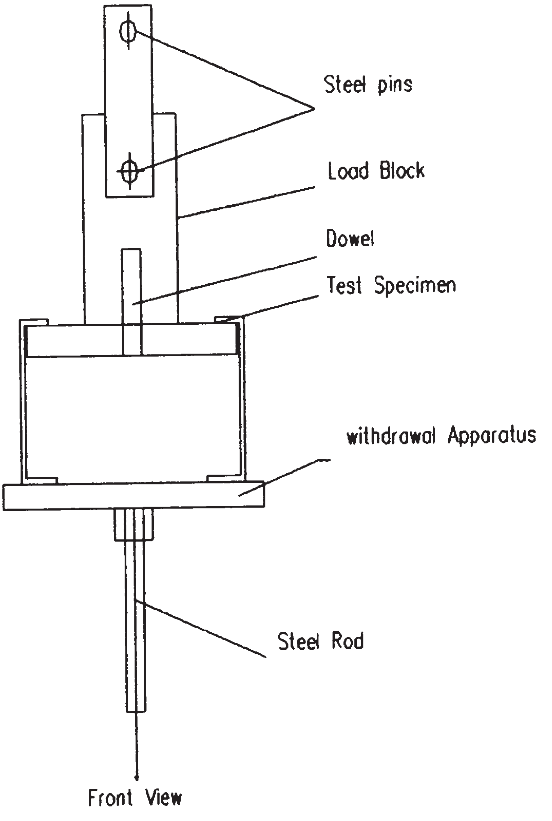

FIG. 4. Face withdrawal test.

TABLE 4. *The results of Duncan test (N/mm²).*

Composite material, withdrawal strength, wood materials, and inner layer	$\bar{X}$	HG	Composite material, withdrawal strength, wood materials, and inner layer	$\bar{X}$	HG
MDF+face+beech+poplar	7.47	A	MDF+edge+mahogany+pine	4.27	B-I
MDF+face+oak+fir	6.37	AB	Pbd+edge+mulberry+poplar	4.17	C-I
MDF+face+walnut+fir	6.37	AB	Pbd+ edge+mahogany+fir	4.12	C-I
MDF+face+mahogany+fir	5.61	BC	MDF+ edge+mahogany+fir	4.06	C-I
MDF+face+mulberry+fir	5.59	BC	Pbd+ face+mahogany+pine	4.01	C-I
MDF+face+beech+pine	5.53	D	Pbd+ face+beech+pine	4.00	C-I
MDF+edge+oak+poplar	5.36	B-E	Pbd+ face+beech+poplar	3.99	C-I
MDF+face+mulberry+pine	5.34	B-F	Pbd+ edge+mahogany+poplar	3.90	C-I
MDF+edge+mahogany+fir	5.21	B-F	Pbd+ face+walnut+pine	3.86	C-I
MDF+face+mahogany+pine	5.16	B-16	MDF+ edge+oak+fir	3.85	C-I
Pbd+face+oak+fir	5.16	B-G	Pbd+ face+beech+fir	3.85	C-I
MDF+face+beech+fir	5.10	B-G	Pbd+ face+oak+poplar	3.80	C-I
MDF+edge+beech+fir	5.10	B-H	Pbd+ face+mulberry+fir	3.80	C-I
MDF+face+oak+poplar	5.06	B-H	Pbd+ face+beech+poplar	3.77	C-I
MDF+face+mulberry+poplar	4.84	B-H	Pbd+ face+mahogany+fir	3.75	C-I
MDF+edge+mulberry+poplar	4.79	B-I	Pbd+ edge+mulberry+pine	3.73	C-I
MDF+edge+walnut+poplar	4.73	B-I	Pbd+ face+walnut+pine	3.73	C-I
MDF+edge+walnut+pine	4.68	B-I	Pbd+ face+mulberry+poplar	3.72	C-I
MDF+edge+mulberry+pine	4.64	B-I	Pbd+ face+mahogany+pine	3.65	C-I
Pbd+face+oak+pine	4.58	B-I	Pbd+ face+beech+pine	3.55	C-I
MDF+face+walnut+pine	4.58	B-I	Pbd+ edge+walnut+pine	3.54	C-I
MDF+face+mahogany+pine	4.52	B-I	Pbd+ edge+mahogany+pine	3.53	C-I
MDF+face+walnut+fir	4.46	B-I	Pbd+ edge+beech+fir	3.48	C-I
Pbd+edge+oak+poplar	4.48	B-I	Pbd+ face+mahogany+fir	3.45	C-I
MDF+face+mahogany+poplar	4.74	B-I	Pbd+ edge+mahogany+poplar	3.37	E-I
MDF+face+beech+poplar	4.46	B-I	MDF+ edge+beech+pine	3.22	F-I
MDF+face+oak+pine	4.38	B-I	Pbd+ face+mahogany+poplar	3.20	F-I
MDF+edge+mahogany+poplar	4.38	B-I	Pbd+ edge+mahogany+fir	3.10	GHI
MDF+edge+oak+pine	4.37	B-I	Pbd+ edge+oak+poplar	2.97	HI
Pbd+face+mulberry+pine	4.36	B-I	Pbd+ edge+oak+pine	2.82	I

LSD value: 1.61

Our data obtained from the withdrawal strength of laminated veneer dowel tests are similar to literature values (Örs, and Özçifçi 1999). Also the value of withdrawal strength of laminated veneer dowels is approximately equal to the value of the withdrawal strength of solid wood dowels. The withdrawal strength of 10-mm-diameter solid beech dowels bonded with PVAc adhesive on the face of MDF is 7.91 N/mm² (Uysal and Özçifçi 2003). Consequently, from the withdrawal strength point, beech wood as a veneer material, MDF as a composite material, face withdrawal strength as the strength of the board, and poplar wood for inner layer for laminated veneer dowels are recommended in the furniture industry. Instead of solid wood dowels, waste veneer materials can also be used in the production of laminated veneer dowels.

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