Abdurrahman Karaman[1]

Effects of Wooden Dowel Species, Edge Banding Thickness, and Adhesive Types on Embedded Strength in Particleboard

Utjecaj vrste drva moždanika, debljine rubnih traka i vrste ljepila na izvlačnu čvrstoću moždanika u iverici

ORIGINAL SCIENTIFIC PAPER
Izvorni znanstveni rad
Received – prispjelo: 17. 4. 2021.
Accepted – prihvaćeno: 13. 12. 2021.
UDK: 544.722.54; 674.812
https://doi.org/10.5552/drvind.2022.2116

ABSTRACT • *Composite materials, edge banding, and wooden dowels are used in inner decoration and construction of furniture frames. However, there is little information available concerning the embedded strength of various fasteners and, in particular, dowels in these materials. The aim of this study was to determine the embedded strengths of PVC edge bandings with the thickness of 0.8, 1, and 2 mm, and dowels produced from five different wood species bonded parallel to the surfaces of a melamine coated particleboard (YL-Lam) with polyvinyl acetate (PVAc-D4) or polyurethane (PUR-D4). In accordance with TS 4539 standard, the effect of wooden dowel species, thickness of edge banding, and type of adhesives on embedded strength were determined. Embedded strength values of polyurethane (PUR-D4) were found 10 % higher than the embedded strength values of polyvinyl acetate (PVAc-D4). The highest embedded strength was obtained for beech dowel bonded with polyurethane (PUR-D4) adhesive in the samples with 0.8 mm PVC edge banding (2.004 N/mm²), while the lowest embedded strength was obtained for Scots pine dowel with polyvinyl acetate (PVAc-D4) adhesive in the samples without PVC edge banding (0.826 N/mm²). This value is higher than the predicted value that allows designers to estimate the embedded strength of dowels.*

KEYWORDS: *PUR-D4; PVC edge banding; embedded strength of dowel; particleboard; dowel*

SAŽETAK • *Pri unutarnjem uređenju i za izradu okvira namještaja upotrebljavaju se kompozitni materijali, rubne trake i drveni moždanici. Međutim, malo je dostupnih podataka o izvlačnoj čvrstoći spojnih elemenata, posebice moždanika. Cilj ovog istraživanja bio je utvrditi izvlačnu čvrstoću moždanika proizvedenih od pet različitih vrsta drva zalijepljenih polivinil acetatnim (PVAc-D4) ili poliuretanskim ljepilom (PUR-D4) u rubove iverice (YL-Lam) paralelno s površinama obloženim melaminom. Rubovi iverice obloženi su PVC trakama debljine 0,8; 1 i 2 mm. Prema standardu TS 4539, određen je utjecaj vrste drva moždanika, debljine rubne trake i vrste ljepila na izvlačnu čvrstoću moždanika. Pokazalo se da su vrijednosti izvlačne čvrstoće moždanika zalijepljenih poliuretanskim ljepilom (PUR-D4) 10 % veće od vrijednosti izvlačne čvrstoće moždanika zalijepljenih polivinil acetatnim ljepilom (PVAc-D4). Najveća izvlačna čvrstoća dobivena je za moždanik od bukovine zalijepljen poliuretanskim (PUR-D4) ljepilom na uzorke s rubnom trakom od PVC-a debljine 0,8 mm (2,004 N/mm²), dok je najniža vrijednost izvlačne čvrstoće zabilježena za moždanik od borovine zalijepljen polivinil acetatnim (PVAc-D4) ljepilom na uzorcima bez PVC rubnih traka (0,826 N/mm²). Ta je vrijednost viša od predviđene vrijednosti koja omogućuje dizajnerima da procijene izvlačnu čvrstoću moždanika.*

KLJUČNE RIJEČI: *PUR-D4; PVC rubna traka; izvlačna čvrstoća moždanika; iverica; moždanik*

[1] Author is associated professor at Uşak University, Vocational School Banaz, Forestry and Forest Program, Department of Forestry, Uşak, Turkey.

1 INTRODUCTION
1. UVOD

Generally, particleboard has been made with forest products in the world. However, due to government restriction, wildlife protection, and other environmental concerns, the availability of these raw materials has been decreasing. The demand for particleboard products continues to increase, leaving an increasing gap between raw materials and products demand (Cheng *et al*., 2004). Dowel joints are widely used in furniture frame construction, both as (load-bearing structure) connections and as simple locators for parts. Joints constructed with dowels may be subjected to withdrawal, bending, shear, and tensional forces. Individual dowel pins used in the joints, however, are subjected to withdrawal and shear forces only (Eckelman and Erdil, 1999).

In order to apply dowel-type joints efficiently, the key thing is to understand their mechanical behavior when undergoing the load (e.g. load-slip relation, stress distributions, ultimate strength and failure modes). The mechanical behavior of wooden joints is a complex problem governed by a number of geometric, solid wood and loading parameters (e.g. wood species, fastener diameter, end distances, edge distances, spacing, number of fasteners, fastener/hole clearances, friction and loading configuration) (Santos *et al.,* 2010). Englesson and Osterman (1972) reported that plain dowels and spiral-grooved dowels with fine grooving gave greater withdrawal strength from the face of particleboard than multi-groove dowels did, 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. Englesson and Osterman (1972) found that applying glue on both walls of the holes and surface of the dowels (double gluing) resulted in a 35 % increase in holding strength compared to coating the walls of holes or surface of the dowels alone.

Edge banding is perceived as the most important accessory and protection in furniture making. Laminates, wood, polyvinyl chloride (PVC), acrylonitrile butadiene styrene (ABS), acrylic, melamine, wood or wood veneer comprise the types of edge banding materials. The purpose of the edge banding is to suppress the absorption of water and humidity, providing a contrasting finish for all decorative surfaces. The edge bands are in the form of 0.4, 0.8, 1 and 2 mm PVC edge bands (Sözen, 2008).

Örs *et al.* (1999a) investigated the effects of the thickness of solid wood edge banding strips on the withdrawal strength of beech dowels in medium-density fiberboard (MDF). Test samples with 5, 8, and 12 mm beech wood edge banding strips were bonded with PVAc adhesive. The study revealed that the highest tensile strength was obtained with MDF covered with 8 mm thick beech wood material (2.294 N/mm^2), while the lowest value was obtained with 10 mm diamater dowel and with unprocessed MDF (1.314 N/mm^2). Dowels of 6, 8, and 10 mm in diameter bonded with PVAc adhesive were tested according to the procedure in ASTM-D 1037 standard 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 6 mm diameter dowel with WFB with 8 mm-thick beech wood, while the lowest value (1.160 N/mm^2) was obtained in 10 mm diameter dowel with unprocessed WFB (Örs *et al.,* 2000). Uysal and Özçifçi (2003) studied 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 polyvinyl acetate (PVAc) and Desmodur-VTKA (D-VTKA). 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. Tankut (2005) presented the results of evaluating the effect of dowel spacing on bending moment capacity of L-type corner joints in 32 mm case construction. Uysal and Kurt (2007) investigated the effects of the thickness of solid wood edge banding strips and dowel diameter on the withdrawal strength of beech dowels in particleboard test samples with 5, 8, and 12 mm beech wood edge banding strips bonded with PVAc adhesive and the holes with 25 mm depth drilled into the edges of the test samples. The results showed that the highest withdrawal strength was obtained in MDF with 6 mm dowel diameter and 5 mm thick solid wood edge banding strip bonded with hot-melt adhesive, while the lowest withdrawal strength was obtained in case of particleboard with no edge banding strip, with 10 mm dowel diameter. Kurt *et al.* (2009) investigated 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. They found that the highest 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, while the lowest withdrawal strength was obtained in particleboard with 10 mm diameter of dowel and without solid wood edge banding. Tankut and Tankut (2010) investigated the effects of the edge banding material, namely polyvinyl chloride (PVC), melamine and wood veneer, thickness of edge banding material (0.4, 1, and 2 mm), and wood composite panel type on the diagonal compression and tension strength properties of particleboard surfaced with synthetic resin sheet (LamPb) and MDF surfaced with synthetic resin sheet (LamMDF). They found that the melamin type edge banding material gave more diagonal tension and compression strength than others. The lowest tension and compression strength was obtained in PVC edge banding material. Yapıcı *et al.* (2011) investigated 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. They found that the highest withdrawal strength was obtained in beech dowels with 8 mm diameter for MDF with 5 mm thickness of solid wood edge banding (6.689 N/mm^2), while the lowest withdrawal strength was obtained in particleboard with 10 mm diameter of dowel and without solid wood edge banding (2.696 N/mm^2).

Vick (1999) reported that the quality of adhesion in adhesives, as well as dispersion on the surface on which the adhesives are applied and penetration to both surfaces, depend on the fluidity of adhesives, which are effective in forming layers and wetting surfaces. Penetration of the hardening adhesives into the porous wood skeleton on several scales are rather complicated. It is strongly influenced by wood factors like wood species, anatomical orientation or surface roughness, adhesive factors, such as adhesive type or viscosity, and process factors, such as applied pressure or temperature, with a big influence on the bonding performance (Kamke and Lee, 2007). D-VTKA adhesive gave higher withdrawal strength values than PVAc. 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 the 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 Eckelman, 2001). Kurt *et al.* (2009) studied the dowel withdrawal strength of the edge banding thickness, dimension of dowels, type of composite materials and adhesives. They reported that D-VTKA adhesive gave higher withdrawal strength values than PVAc and hot-melt adhesives. Uysal and Kurt (2007) found that the withdrawal strength of dowels with D-VTKA adhesive gave higher withdrawal strength values than PVAc and hot melt adhesives. In the literature, some authors reported that the bond strength for PUR adhesives was higher than the joint strength of PVAc adhesives (Sterley *et al*., 2004; Bomba *et al*., 2014).

This study was performed (1) to evaluate the effects of thickness of edge banding (control, 0.8, 1, and 2 mm) on the embedded strength, (2) to determine the effects of wooden dowel species, namely, beech, chestnut, olive, Scots pine and Turkish fir on the embedded strength, (3) to evaluate adhesive types, namely, polyvinyl acetate (PVAc-D4) and polyurethane (PUR-D4) on the embedded strength.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Materials
2.1. Materijali

The following composite test panel was used. Melamine coated particleboard (YL-Lam) was provided by Güçlüer Forest Products Industry and Trade Ltd. Company (Uşak, Turkey). **Average moisture content, density, bending strength (***MOR*) and modulus of elasticity (*MOE*) of the YL-Lam were determined to be 7.5 %; 0.620 g/m^3; 19.20 N/mm^2 and 2620 N/mm^2.

The wood of beech (*Fagus orientalis* Lipsky), Scots pine (*Pinus sylvestris* Lipsky), Turkish fir (*Abies bornmülleriana* Mattf.), and Chestnut (*Castanea sativa* Mill) is used extensively in the wood construction sector. This wood was also used as dowel material for these experiments. The wood was chosen randomly from timber merchants of Ankara, Turkey, while the Olive wood (*Ole europaea* L.) as massive material was obtained from the timber enterprises in Akhisar district of Manisa, Turkey. A special emphasis was put on the selection of wood material. Accordingly, non-deficient, proper, knotless, normally grown (without zone line, reaction wood, decay, insect and mushroom damages) wood material was selected. In accordance with TS 2472 (1976), the air-dry density properties of wood materials used in this study are shown in Table 1. The wood dowels were prepared with a cylindrical shape in nominal dimensions of 8 mm × 70 mm (Figure 1).

PVC edge banding is manufactured from first-quality resins and high-impact modifiers resulting in a product of excellent machinability, impact resistance, durability, and overall appearance. The edge bands, which are commonly used in the furniture industry, are in the form of PVC (polyvinyl chloride) edge bands of 0.4, 0.8, 1, and 2 mm. The PVC edge bands with the thickness of 0.8, 1, and 2 mm were used in this study.

The polyvinyl acetate (PVAc) and polyurethane, which are commonly used in the wood industry and box- type furniture manufacture, were used in this study. The single-component polyvinyl acetate (PVAc) adhesive, Kronen Holzleim D4, manufactured by the German Kronen Company (Fenstertechnik Institut Rosenheim, Germany) was used in this study. Polyvinylacetate adhesive, which falls into durability class D4 according to DIN EN 204 (2016), was used as an adhesive. This polyvinylacetate glue, odorless and fireproof, is easy to apply, has quick setting and it is applied

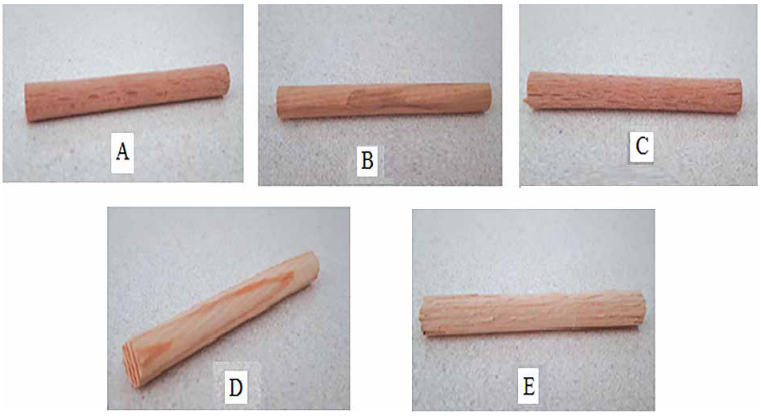

Figure 1 Types of dowel woods used in experiments: A) Beech, B) Olive, C) Chestnut, D) Scots pine, E) Turkish fir
Slika 1. Moždanici od različitih vrsta drva upotrijebljenih u istraživanju: A) bukovina, B) maslinovina, C) kestenovina, D) borovina, E) drvo turske jele

Table 1 Density of wood species used in my research
Tablica 1. Gustoća drva obuhvaćenog istraživanjem

Wood material and wood composite material *Drvni materijal i drvno-kompozitni materijal*	D_{12}, g/cm^3
Beech (*Fagus orientalis* Lipsky)	0.65
Chestnut (*Castanea sativa* Mill)	0.57
Scots pine (*Pinus sylvestris* Lipsky)	0.50
Turkish fir (*Abies bornmülleriana* Mattf.)	0.42
Olive (*Olea europaea*)	0.84

D_{12} – Air dry density at 20 °C and 65 % relative humidity / *gustoća drva sušenoga pri 20 °C i 65 %-tnoj relativnoj vlažnosti zraka*

cold. According to the producer's recommendations, the adhesive was applied in the amount of (180±10) g/m^2 to the surfaces. The properties of this glue were determined as follows: press compression 0.1-0.8 N/mm^2, pH 3.5, viscosity (20 °C) 16000-15000 mPas, density 1.08 g/cm^3 and wood bonding time at 20 °C for 35-40 minutes, by the company (Kronen, 2019). The polyurethane (PUR-D4; Egger Decor, Gebze, Kocaeli, Turkey) is a single component polyurethane-based adhesive, fast curing and polyurethane-based wood adhesive. The gluing process was carried out at 20 °C and 65 % relative humidity. According to the producer's recommendations, the adhesive was applied in the amount of (180±10) g/m^2 to the surfaces. It is easy to apply, water-resistant and has low viscosity and high bonding strength. (Romabant, 2019). In this study, the hot-melt was used as a thermoplastic synthetic resin, commonly used as PVC edge banding adhesive in the furniture industry. Its application is recommended in locations subjected to 8 - 10 % relative humidity. The temperature for the adhesive gluing was 200 - 230 °C.

2.2 Preparation of test samples
2.2. Priprema ispitnih uzoraka

Wood materials were held for approximately 3 months in the conditioning room at (20±2) °C and (65±3) % relative humidity until their weight became stable. Then, 1000 mm ×11 mm ×11 mm pieces were cut from beech sapwood, Scots pine sapwood, Turkish fir sapwood, Chestnut sapwood and olive sapwood. Dowels with 8 mm diameter were produced from these pieces using a dowel machine. These dowels were produced striated. Then, in total 200 samples were prepared for this study (YL-Lam, two different adhesives PVAc-D4, PUR-D4, five different wooden dowel species, three different PVC edge banding with the thickness of 0.8 mm, 1 mm, 2 mm and control). YL-Lam material was prepared as follows: Randomly chosen YL-Lam board was cut into 200 pieces for each member in the dimensions of (18 mm × 75 mm × 75 mm) ± 1 mm with a wood milling machine. An amount of 150 pieces for each composite material was banded on one edge with three different types of edge banding (PVC edge bands with the thickness of 0.8 mm, 1 mm, and 2 mm). The PVC bands were banded by using a hot-melt adhesive on the edge banding machine (Figure 2). In addition, 50 pieces were not included into any process. Dowels of 25 mm depth for embedded tests were glued into matching holes and were drilled into each specimen according to the TS 4539 (1985) standard. All holes were drilled with standard twist drills. The diameter of the holes was 8 mm. Before the dowels were inserted, adhesives (180 g/m^2) were applied both on the sides of the dowels and on the surfaces of the holes. The configuration of test samples is shown in Figure 2. Before the embedded test, the samples were stabilized at (20±2) °C and (65±3) % relative humidity until the samples had 12 % moisture content.

2.3 Test method
2.3. Ispitna metoda

All tests were carried out on a universal testing machine, ZwickRoell Z050, placed in the laboratory of Gümüşhane University and Gümüşhane Vocational High School, having a capacity of 50 kN and equipped with jigs to hold the specimens as shown in Figure 3. A loading rate of 5 mm/min was used in all tests according to ASTM 1037 (1988) standards. The embedded strength was determined as Eq. 1:

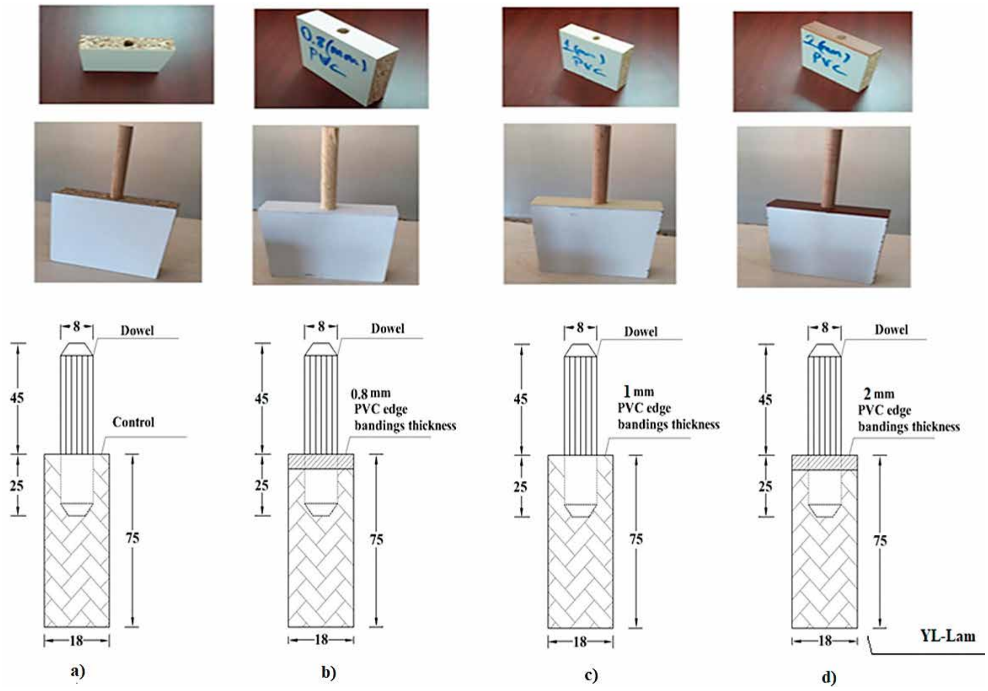

Figure 2 Configuration of test samples; a) Control (non-edge banding), b) 0.8 mm edge banding, c) 1 mm edge banding, d) 2 mm edge banding
Slika 2. Konfiguracija ispitnih uzoraka: a) kontrolni uzorak (bez rubnih traka), b) uzorak s rubnom trakom od 0,8 mm, c) uzorak s rubnom trakom od 1 mm, d) uzorak s rubnom trakom od 2 mm

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

Where is embedded strength (N/mm^2), F_{max} is the maximum load (N), r is radius of dowel (mm), h is depth of dowel (mm).

2.4 Data analyses
2.4. Analiza podataka

The multiple variance analysis was performed to determine the differences among the factors (wooden dowel species, thickness of PVC edge banding, adhesive types) by using the SPSS program (Statistical Software, a computer-based statistical package, version 22). The Tukey's test was used to determine if there was a meaningful difference among the groups.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

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

For the samples without PVC edge banding (control), the highest embedded strength was obtained from the Beech dowel bonded with PUR-D4 adhesive (1.616 N/mm^2), while the lowest embedded strength was obtained from the Scots pine dowel with PVAc-D4 adhesive (0.826 N/mm^2). In terms of the embedded strength values of used PVC edge banding with the thickness of 0.8 mm, the highest embedded strength was obtained

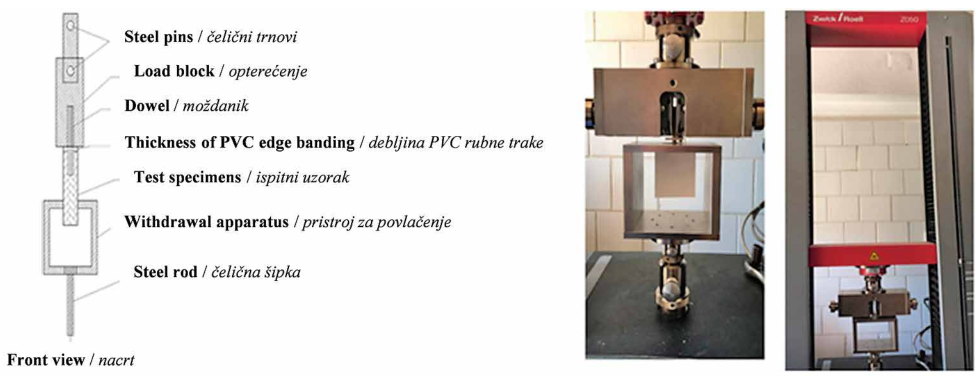

Figure 3 Apparatus used to hold specimens for embedded strength tests
Slika 3. Pristroj za prihvat uzoraka za ispitivanja izvlačne čvrstoće

Table 2 Average values of embedded strength (N/mm²)
Tablica 2. Srednje vrijednosti izvlačne čvrstoće (N/mm²)

Factor source / *Čimbenik*		$\bar{x}$	*SD*	HG
Adhesive type *Vrsta ljepila*	PUR-D4	1.298 (22.34)*	0.29	A
	PVAc-D4	1.176 (29.71)	0.35	B
Thickness of PVC edge banding *Debljina PVC rubne trake*	Control	1.176 (24.66)	0.29	B
	0.8 mm	1.485 (25.60)	0.38	A
	1 mm	1.192 (23.50)	0.28	B
	2 mm	1.096 (20.07)	0.22	B
Wooden dowel species *Vrsta drva moždanika*	Beech / *bukovina*	1.342 (29.06)	0.39	A
	Chestnut / *kestenovina*	1.217 (20.54)	0.25	A
	Olive / *maslinovina*	1.278 (24.26)	0.31	A
	Scots pine / *smrekovina*	1.047 (25.79)	0.27	B
	Turkish fir / *drvo turske jele*	1.301 (25.36)	0.33	A

*Values in the parentheses are coefficients of variation, *SD* – Standard deviation, HG – Homogeneity group.
**Vrijednosti u zagradama koeficijenti su varijacije, SD – standardna devijacija, HG – grupa homogenosti.*

Table 3 Average values of interaction for embedded strength (N/mm²)
Tablica 3. Srednje vrijednosti interakcije za izvlačnu čvrstoću (N/mm²)

Thickness of PVC edge bandings *Debljina PVC rubne trake*	**Wooden dowel species** *Vrsta drva moždanika*	**Adhesives** *Ljepilo*	$\bar{x}$	*SD*
Control / *kontrolni uzorci*	Beech / *bukovina*	PVAc-D4	1.322	0.12
		PUR-D4	1.616	0.29
	Chestnut / *kestenovina*	PVAc-D4	1.124	0.21
		PUR-D4	1.358	0.14
	Olive / *maslinovina*	PVAc-D4	1.264	0.22
		PUR-D4	0.964	0.19
	Scots pine / *borovina*	PVAc-D4	0.826	0.16
		PUR-D4	0.965	0.19
	Turkish fir / *drvo turske jele*	PVAc-D4	1.124	0.26
		PUR-D4	1.196	0.24
0.8 mm	Beech / *bukovina*	PVAc-D4	1.280	0.20
		PUR-D4	2.004	0.39
	Chestnut / *kestenovina*	PVAc-D4	1.024	0.37
		PUR-D4	1.498	0.13
	Olive / *maslinovina*	PVAc-D4	1.612	0.33
		PUR-D4	1.554	0.37
	Scots pine / *borovina*	PVAc-D4	1.248	0.22
		PUR-D4	1.394	0.13
	Turkish fir / *drvo turske jele*	PVAc-D4	1.426	0.28
		PUR-D4	1.806	0.31
1 mm	Beech / *bukovina*	PVAc-D4	1.236	0.38
		PUR-D4	1.176	0.23
	Chestnut / *kestenovina*	PVAc-D4	0.952	0.22
		PUR-D4	1.328	0.15
	Olive / *maslinovina*	PVAc-D4	1.485	0.13
		PUR-D4	1.186	0.09
	Scots pine / *borovina*	PVAc-D4	1.032	0.27
		PUR-D4	0.868	0.07
	Turkish fir / *drvo turske jele*	PVAc-D4	1.348	0.11
		PUR-D4	1.306	0.38
2 mm	Beech / *bukovina*	PVAc-D4	0.914	0.18
		PUR-D4	1.190	0.11
	Chestnut / *kestenovina*	PVAc-D4	1.170	0.16
		PUR-D4	1.280	0.14
	Olive / *maslinovina*	PVAc-D4	1.010	0.17
		PUR-D4	1.146	0.08
	Scots pine / *borovina*	PVAc-D4	1.066	0.37
		PUR-D4	0.980	0.20
	Turkish fir / *drvo turske jele*	PVAc-D4	1.054	0.19
		PUR-D4	1.146	0.32

from samples with Beech dowel bonded with PUR-D4 adhesive, while the lowest embedded strength was obtained from Chestnut dowel with PVAc-D4 adhesive. When the samples with 1 mm PVC edge banding was examined, the highest embedded strength was obtained from Olive dowel bonded with PVAc-D4 adhesive (1.485 N/mm^2), while the lowest embedded strength was obtained from Scots pine dowel with PVAc-D4 adhesive (0.868 N/mm^2). When embedded strength values of used PVC edge banding with the thickness of 2 mm was considered, the highest embedded strength was obtained with PUR-D4 adhesive, while the lowest embedded strength was obtained from Beech dowel with PVAc-D4 adhesive (Table 3).

The reasons for this are the density differences of wood materials, structural properties, mechanical properties and provided better bonding strength. The density of beech wood was higher than the density of the other woods used in the experiments. This may be due to the thick cell walls of beech wood, large number of tracheae, narrow lumen space and high material density, and thin lumen of the cell walls in Scots pine and low material density. An excess density may have caused the surface area in contact with each other to grow and increase the amount of molecules involved in adhesion, hence the molecules to adhere to each other by creating more adhesion force. In addition, in trees with an excess density, hydrogen bridges formed between the cellulose molecules of the wood material and the hydroxyl groups (OH) of the glue are deemed more excessive.

As polyurethane (PUR-D4) cures, it swells and fills the gaps in the dowel holes, resulting in better mechanical adhesion. According to the results, if the hole wall of the dowel and surface of the dowel are smoother than the PVAc-D4, it gives better mechanical adhesion with dowels.

Results of multiple variance analysis of the impact of adhesive types, the thickness of PVC edge banding, and wooden dowel species for dowel embedded strength are given in Table 4.

The effects of the main factors including the adhesive types (A), thickness of PVC edge banding (B), and wooden dowel species (C) were found to be statistically significant at the level of 0.05. All two-way interactions were also statistically significant ($p \leq 0.05$). Three factor interactions of adhesive types × thickness of PVC edge banding × wooden dowel species (A × B × C) were statistically insignificant ($p \leq 0.05$). Tukey's test was carried out in order to determine these differences and results are given in Table 2.

With respect to the mean values in Table 2, regarding the adhesive types, the dowel embedded strength was found to be the highest in the polyurethane adhesive (PUR-D4). The dowel embedded strength values of polyurethane PUR-D4) were found 10 % higher than the embedded strength values of polyvinyl acetate (PVAc-D4). The PUR-D4 adhesive expands its volume after being applied to the wood material.

For the thicknesses of PVC edge banding, the dowel embedded strength of 0.8 mm PVC edge banding was approximately 25 %, 26 % and 35 % higher than for 1 mm PVC edge banding, the samples with control (without PVC edge banding), and 2 mm PVC edge banding, respectively (Table 2). It has been determined that the dowel tensile strength increases when the edges of the YL-Lam board are covered with a PVC edge band. These values correspond to the values given in the literature (Örs *et al*., 1999; Tankut and Tankut 2010; Yapici *et al.,* 2011).

Örs *et al.* (1999b) reported that the tensile strength of dowels increases if the edges of the YL board are massified. YL boards without solid edges show lower

Table 4 Results of multiple variance analysis of dowel embedded strength
Tablica 4. Analiza varijance višestruke linearne regresije rezultata izvlačne čvrstoće moždanika

Source of variance / *Izvor varijacije*	*df.*	**Sum of square** *Zbroj kvadrata*	**Mean square** *Sredina kvadrata*	***F* value**	***P* value**
Adhesive types (A)[a] / *vrsta ljepila* (A)[a]	1	0.746	0.746	13.434	0.000
Thickness of PVC edge banding (B)[b] *debljina PVC rubne trake* (B)[b]	3	4.355	1.452	26.147	0.000
Wooden dowel species (C)[c] / *vrsta drva moždanika* (C)[c]	4	2.128	0.532	9.585	0.000
A × B	3	0.895	0.298	5.375	0.001
A × C	4	1.425	0.356	6.418	0.000
B × C	12	2.134	0.178	3.203	0.000
A × B × C	12	0.832	0.069	1.249	0.254*
Error / *pogreška*	160	8.883	0.056		
Total / *ukupno*	200	327.399			
Corrected Total / *ispravljeno ukupno*	199	21.397			
Squared = .585 (Adjusted R Squared = .484)					

*Not significant, *df* – Degrees of freedom, [a]Adhesive types (PVAc-D4, PUR-D4), [b]Thickness of PVC edge banding (0.8, 1 and 2 mm), [c]Wooden dowel species (Beech, Chestnut, Olive, Scots pine, Turkish fir)
**Nije značajno, df – stupnjevi slobode, [a]vrsta ljepila* (PVAc-D4, PUR-D4), [b]*debljina PVC rubne trake (0,8; 1 i 2 mm), [c]vrsta drva moždanika (bukovina, kestenovina, maslinovina, borovina i drvo turske jele).*

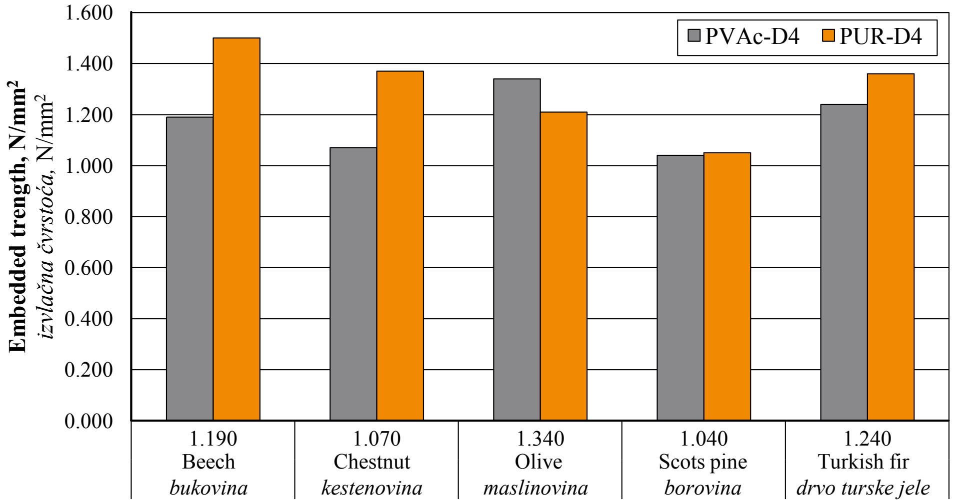

Figure 4 Effect of interactions of types of adhesives and wooden dowel species on embedded strength
Slika 4. Utjecaj interakcije vrste ljepila i vrste drva moždanika na izvlačnu čvrstoću

tensile strength than solid YL boards. Tankut and Tankut (2010) reported that the highest compression strength was obtained in 0.4 mm melamine edge banding, the lowest in PVC edge banding with 1 mm thickness. Yapici *et al.* (2011) determined that the highest withdrawal strength was obtained in beech dowels with 5 mm thickness of solid wood edge banding of beech bonded with D-VTKA adhesive.

For wooden dowel species, the highest embedded strength values of wooden dowel species were obtained from beech. The lowest embedded strength values of dowels were obtained from samples taken from chestnut and Scots pine (Table 2). It is inferred from the results that the highest embedded strength was obtained due to the density of the solid wood. Likewise, in their study, Özcan *et al.* (2013) observed that the highest withdrawal strength values were obtained from dowels made from oak and beech.

Interactions between adhesive type and wooden dowel species, adhesive type and thickness of PVC edge banding wooden dowel species and thickness of PVC edge banding are given Figure 4, 5 and 6.

As shown in Figure 4, the highest average embedded strength was observed in the beech dowel with PUR-D4, while the lowest average embedded strength was observed in Scots pine dowel with PVAc-D4.

As indicated in Figure 5, the samples of PUR-D4 adhesive with 0.8 mm thickness of PVC edge banding showed the highest average embedded strength, the PVAc-D4 with 2 mm thickness of PVC edge banding showed the lowest average embedded strength.

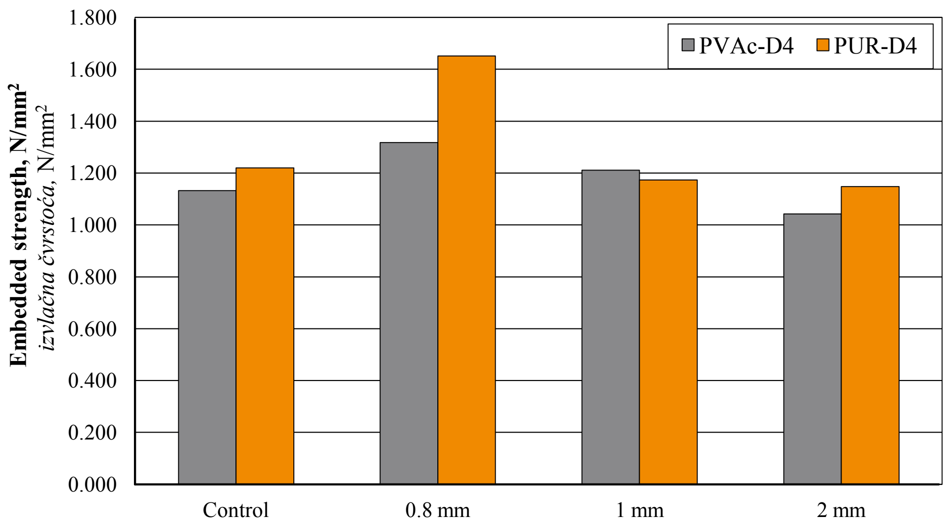

Figure 5 Effect of interactions of types of adhesives and thickness of PVC edge banding on embedded strength
Slika 5. Utjecaj interakcije vrste ljepila i debljine PVC rubne trake na izvlačnu čvrstoću

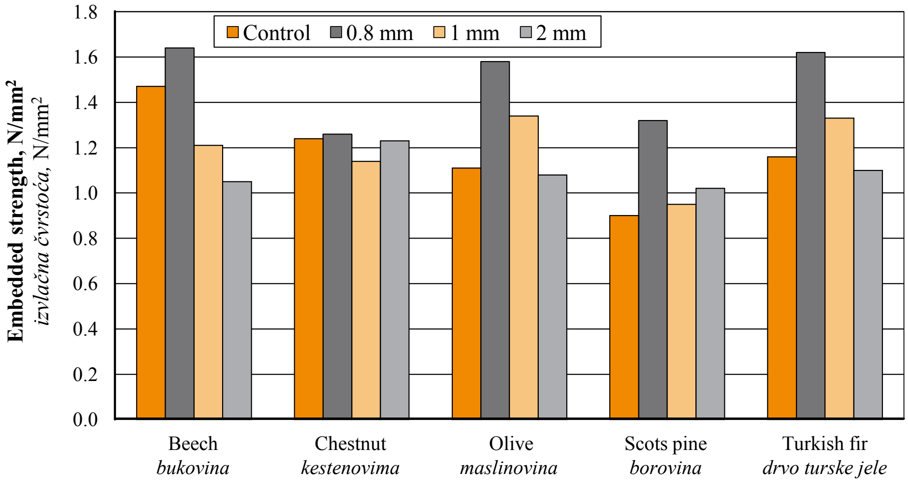

Figure 6 Effect of interactions of thickness of PVC edge banding and wooden dowel species on embedded strength
Slika 6. Utjecaj interakcije debljine PVC rubne trake i vrste drva moždanika na izvlačnu čvrstoću

4 CONCLUSIONS
4. ZAKLJUČAK

The joints assembled with polyurethane (PUR-D4) adhesive had 10 % higher embedded strength than the joints glued with polyvinyl acetate (PVAc-D4) adhesive. As polyurethane (PUR-D4) cures, it swells and fills the gaps in the dowel holes, resulting in better mechanical adhesion. According to the results, if the hole wall of the dowel is smoother than the adhesives, it provides better mechanical adhesion with dowels.

The beech dowel had the highest embedded strength values, and there were significant differences between these five wooden dowel species in this study. The reasons for this may be due to the density of wooden materials.

In terms of embedded strength of dowels from the edges of YL-Lam, PVC edge banding with 0.8 mm thickness was 25 % higher than PVC edge banding with 1 mm, 26 % higher than the control (without edge banding), and 36 % higher than PVC edge banding with 2 mm.

The highest embedded strength values were obtained with the beech dowel as the wooden dowel species, polyurethane (PUR-D4) as the adhesive, PVC edge banding with 0.8 mm thickness as the edge band. According to the results, if the hole wall and surface of the dowel are smoother, then the adhesives provide better mechanical adhesion with dowels and YL-Lam. Moreover, if the dowels are subjected to embedded strength, it is advised that beech dowel should be used on YL-Lam with polyurethane (PUR-D4) as the adhesive in the case-type furniture.

As a result, in building elements where adhesion performance is important, it may be recommended to use beech dowels, which are especially high in density, if wood material is to be used. In addition, since the highest tensile strength occurs in the combination of 0.8 mm thick PVC edge band, polyurethane adhesive, and beech dowel, applying these criteria in dowel joints will provide an advantage.

5 REFERENCES
5. LITERATURA

1. Bomba, J.; Sedivka, P.; Böhm, M.; Devera, M., 2014: Influence of moisture content on the bond strength and water resistance of bonded wood joints. BioResources, 9 (3): 5208-5218. https://doi.org/10.15376/biores.9.3.5208-5218
2. Cheng, E.; Sun, X.; Karr, G. S., 2004: Adhesive properties of modified soybean flour in wheat straw particleboard. Composites Part A: Applied Science and Manufacturing, 35 (3): 297-302. https://doi.org/10.1016/j.compositesa.2003.09.008
3. Eckelman, C. A.; Erdil, Y. Z., 1999: Joint design manual for furniture frames constructed of plywood and oriented strand board. In: Proceeding of 1st International Furniture Congress Proceedings. Istanbul, Turkey, pp. 266-268.
4. Erdil, Y. Z.; Eckelman, C. A., 2001: Withdrawal strength of dowels in plywood and oriented strand board. Turkish Journal of Agricultural Forestry, 25 (5): 319-327.
5. Englesson, T. A.; Osterman, A., 1972: Assembly of chipboard with round dowels. Swedish Forest Products Reseach Laboratory, Stockholm, Report No. 28.
6. Kamke, F. A.; Lee, J. N., 2007: Adhesive penetration in wood: a review. Wood and Fiber Science, 39 (2): 205-220.
7. Kronen, 2019: PVAc-D4 White Adhesive, İzmir._(online). https://www.kronen.com.tr/pva-d4-beyaz-tutkal (Accessed Oct 14., 2019).
8. Kurt, S.; Uysal, B.; Özcan, C.; Yildirim, M. N., 2009: The effects of edge banding thickness of uludağ bonded with some adhesives on withdrawal strengths of beech dowel pins in composite materials. BioResources, 4 (4): 1682-1693. https://doi.org/10.15376/biores.4.4.1682-1693
9. Romabant, 2019: Industrial Glues Professional Adhesive Solution. Kocaeli.
10. Örs, Y.; Atar, M.; Özçifçi, A., 1999a: Tensile resistance of dowel with the pvac and polymerin from different types

wood or particle or fiberboards. Turkish Journal of Agriculture and Forestry, 23 (1): 151-156.
11. Örs, Y.; Atar, M.; Özçifçi, A., 1999b: Effects of edge covering on tensile strength of MDF. Pamukkale University Engineering College Journal of Engineering Sciences, 5 (2-3): 1173-1177.
12. Özcan, C., Uysal, B., Kurt, Ş.; Esen, R., 2013: Effect of dowels and adhesive types on withdrawal strength in particleboard and MDF. Journal of Adhesion Science and Technology, 27 (8): 843-854. https://doi.org/10.1080/01694243.2012.727157
13. Santos, C. L.; De Jesus, A. M. P.; Morais, J. J. L.; Lousada, J. L. P. C., 2010: A comparison between the EN 383 and ASTM D 5764 test methods for dowel-bearing strength assessment of wood: experimental and numerical ınvestigations. Strain, 46 (2): 159-174. https://doi.org/10.1111/j.1475-1305.2008.00570.x
14. Sözen, E., 2008: Effect of type and thickness of edge banding materials on the strength of corner joints used case furniture. Master Thesis, Zonguldak Karaelmas University. Graduate School of Natural and Applied Sciences, Zonguldak.
15. Sterley, M.; Blümer, H.; Wålinder, M. E. P., 2004: Edge and face gluing of green timber using a one-component polyurethane adhesive. Holz Roh- Werkstoff, 62: 479-482. https://doi.org/10.1007/s00107-004-0517-7
16. Tankut, A. N., 2005: Optimum dowel spacing for corner joints in 32-mm cabinet construction. Forest Product Journal, 55 (12): 100-104.
17. Tankut, A. N.; Tankut, N., 2010: Evaluation the effects of edge banding type and thickness on the strength of corner joints in case-type furniture. Materials and Design, 31: 2956-2963. https://doi.org/10.1016/j.matdes.2009.12.022
18. Uysal, B.; Özçifçi, A., 2003: Effects of dowels produced from various materials on withdrawal strength in MDF and PB. Journal of Applied Polymer Science, 88(2): 531-535.
19. Uysal, B.; Kurt, S., 2007: The effect of edge banding thickness of white oak bonded with different adhesives on withdrawal strengths of beech dowels in composite material. Journal of Adhesion Science and Technology, 21 (8): 735-744. https://doi.org/10.1163/156856107781362626
20. Vick, C. B., 1999: Adhesive bonding of wood materials. In: Wood Handbook: Wood as an Engineering Material. Forest Products Laboratory, pp. 9-1 – 9-24.
21. Yapici, F.; Likos, E.; Esen, R., 2011: The effect of edge banding thickness of some trees on withdrawal strength of beech dowel pins in composite material. Wood Research, 56 (4): 601-612.
22. ***ASTM D1037, 1998: Standard test method for evaluating properties of wood-base fiber and particle panel materials. ASTM International. West Conshohocken, PA.
23. ***DIN EN 204, 2016: Classification of thermoplastic wood adhesives for non-structural applications.
24. ***TS 2472, 1976: Wood – determination of density for physical and mechanical tests. TSE, Ankara, Turkey.
25. ***TS 4539, 1985: Wood joints-rules of dowel joint. TSE, Ankara, Turkey.

Corresponding address:

Assoc. Prof. ABDURRAHMAN KARAMAN, PhD
Uşak University, Vocational School Banaz, Forestry and Forest Program, Department of Forestry, Uşak, TURKEY, e-mail: abdurrahman.karaman@usak.edu.tr