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Effect of Epoxy Resin Reinforcement on Screw Withdrawal Strength of Fiberboard and Particleboard Used in Furniture Industry

Utjecaj ojačanja epoksidnom smolom na izvlačnu silu vijka u ploča vlaknatica i iverica koje se rabe u proizvodnji namještaja

ORIGINAL SCIENTIFIC PAPER
Izvorni znanstveni rad
Received – prispjelo: 3. 8. 2023.
Accepted – prihvaćeno: 10. 11. 2023.
UDK: 674.812
https://doi.org/10.5552/drvind.2023.0146

ABSTRACT • *The study aimed to increase the screw withdrawal strength of medium density fiberboard and particleboard used in furniture strength by using epoxy resin in the screw pilot hole. Therefore, the effects of pilot hole diameters, screw diameter, and amount of epoxy resin on screw withdrawal strength of medium density fiberboard and particleboard from face and edge were investigated. According to TS EN 13446, 50 mm × 50 mm specimens were cut from commercial medium density fiberboard and particleboard boards. A static load was applied parallel to the screw direction. The screw withdrawal strength of medium density fiberboard was higher than the screw withdrawal strength of particleboard because of its density. Besides, the screw withdrawal strength of medium density fiberboard and particleboard samples with a 3.5 mm screw diameter was higher compared to those with a 4.5 mm screw diameter. A decrease in pilot hole diameter and an increase in the amount of epoxy resin provided higher screw withdrawal strength of materials. Using 20 % epoxy resin of the volume of the pilot hole resulted in two times better screw withdrawal strength values. The study showed that a higher amount of epoxy resin, smaller pilot hole diameter, and smaller screw diameter contribute to better screw withdrawal strength of both medium density fiberboard and particleboard from the face and edge.*

KEYWORDS: *epoxy resin; reinforcement; screw withdrawal strength; medium density fiberboard; particleboard*

SAŽETAK • *Cilj ovog istraživanja bio je povećati izvlačnu silu vijka u ploča vlaknatica i iverica koje se rabe u proizvodnji namještaja, i to upotrebom epoksidne smole u pilot-rupama za vijke. Stoga je ispitan utjecaj promjera pilot-rupa, promjera vijka i količine epoksidne smole na izvlačnu silu vijka na plohi i rubu ploče vlaknatice i iverice. Uzorci dimenzija 50 mm × 50 mm prema TS EN 13446 izrađeni su od komercijalne srednje guste ploče vlaknatice i ploče iverice. Statičko opterećenje djelovalo je paralelno na smjer vijka. Zbog razlika u gustoći ploča*

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izvlačna sila vijka bila je veća za srednje gustu ploču vlaknaticu nego za ploču ivericu. Osim toga, izvlačna sila vijka promjera 3,5 mm u srednje gustoj ploči vlaknatici i ploči iverici bila je veća od izvlačne sile vijka promjera 4,5 mm. Smanjenje promjera pilot-rupe i povećanje količine epoksidne smole omogućilo je veću otpornost materijala na izvlačenje vijaka. Upotrebom 20 % epoksidne smole u odnosu prema volumenu pilot-rupe rezultiralo je dvostruko boljim vrijednostima izvlačne sile vijka. Istraživanje je pokazalo da veća količina epoksidne smole, manji promjer pilot-rupe i manji promjer vijka pridonose boljoj izvlačnoj sili vijka na plohi i rubu srednje guste ploče vlaknatice i ploče iverice.

KLJUČNE RIJEČI: *epoksidna smola; ojačanje; izvlačna sila vijka; srednje gusta ploča vlaknatica; ploča iverica*

1 INTRODUCTION
1. UVOD

Joints are the weakest component of furniture construction (Smardzewski, 2009). In the case of any joint failure, all construction fails. Therefore, the reusability of the furniture decreases over time due to the fact that furniture joints loosen or cannot provide its serviceability. Especially, in case furniture, screw joints are a typical example where a furniture member or screw is not damaged, but the screw hole enlarge. Besides, screws are used for demountable furniture to be easily assembled and disassembled. However, screw holes enlarge after screwing off, so the screw pilot hole diameter increases and the joint does not have the initial strength after re-assembly. Larger screws could be preferred for re-assembly efforts, which increases the strength of the screw joints because the pilot hole diameter was increased in that screw withdrawn from the material (Uysal *et al.,* 2015). However, the use of larger joints may not be suitable for wood-composite materials, especially edgewise, because of their thickness and internal bond strength. On the contrary, the use of adhesive in screw pilot holes is another method to increase the screw withdrawal strength (*SWS*) of materials. Epoxy resin (EP) is a better selection to reinforce screw withdrawal strength compared to other adhesives because it provides higher mechanical properties for adhesives containing EP as reinforcement.

An increase in joint strength decreases the environmental impact of furniture because its serviceability and life span are increased since the rate of discarded furniture in landfills decreases while the rate of reusability increases. Besides, the repairability of the furniture construction with larger screws or the use of adhesive could increase the life span of the furniture. Remanufacturing furniture is another way to increase furniture life span and decrease its environmental impact before being discarded in landfills. However, the remanufacturing market of furniture is responsible for 0.4 % of the furniture industry, and the number of employees is less compared to employees in the reuse network (Parker *et al.,* 2015). In addition, furniture remanufacturing requires more energy than furniture reuse, according to the product recovery hierarchy in the end-of-life options (Östlin *et al.,* 2009). Hence, increasing the service life of furniture with screw joints could be provided by increasing the *SWS* of materials used in construction, so the second users can reuse furniture after it fulfills its service life for the first users.

Screw-type joints are mainly used in demountable furniture for easy assembly and disassembly. Therefore, it should be considered how joint strength would be increased after the first use or dissembling. Fasteners like screws, minifixes, confirmats, etc. are effective joinery systems to join elements made of wood-based composites and are used in case furniture. The strength of joints depends on the material, joinery system, screw pilot hole, number of fasteners and distance between fasteners. However, it is significant to have a self-locking system for each fastener to hold material. In addition, freezing and heating significantly affect material withdrawal capacity (Gašparík *et al.,* 2023). Thus, increasing the *SWS* of materials comes into prominence to improve the overall strength of furniture joints. It depends on their density and internal bonding strength, diameter of pilot hole, length of screw penetration, diameter of screw shank and thread, and filling material injected in a pilot hole (Smardzewski *et al.,* 2016). Besides, thread geometry such as thread height, flank distance, teeth angle, and thread angle significantly affect the *SWS* of the material (Hoelz *et al.,* 2022).

Fiberboard (MDF) and particleboard (PB) are widely used as raw materials for Ready-to-Assembly (RtA) furniture. Screw-type fasteners are not only used in joints but also in handles, hinges and locks (Örs *et al.,* 1998). Studies related to joints with screws have been conducted with the technological development in wood composites and engineered wood since the strength design of furniture was defined in the 1940s (Eckelman, 1973; Smardzewski, 2009; Uysal and Haviarova, 2019). Such studies will continue to be conducted to enhance the strength of screw joints as long as the furniture is the greatest need of people's living spaces and as long as new technological developments emerge in the field. The *SWS* of material increased by 9-45 % and 7-39 % with injected polyvinyl acetate adhesive in pilot holes for MDF and PB compared to those without adhesive. In addition, an increase in the thread depth of the screw provided higher *SWS* (Örs *et al.,* 1998). The correlation between *SWS* and internal bonding strength is better than that of density and was studied to predict the internal bond strength of PB from its *SWS* (Semple and Smith, 2005). The larger-diameter screws had a greater *SWS* than smaller-diameter screws, but thread depth is more critical than screw diameter for the *SWS* of materials (Abu and Ahmad, 2015). Polyvinyl acetate and polyurethane adhesive were used in screw pilot holes to increase joint strength in RtA furniture (Imirzi *et al.,* 2016). The type of material and type of screw affected the *SWS* of the material (Wolpiuk and Sydor, 2016). The *SWS* of a material increases with higher material density (Bal *et al.,* 2017; Jivkov *et al.,* 2017). The *SWS* of wood-based materials was inversely proportional to the modulus of elasticity because of high stiffness (Yunus *et al.,* 2019). The effects of screw type, screw orientation, and adhesive on the *SWS* of MDF and PB were studied. Results showed that the use of adhesive in pilot holes increased the *SWS* of both MDF and PB (Yorur *et al.,* 2020). The pilot hole diameter and density effects on the *SWS* of MDF were studied. Results revealed that pilot diameter had more impact on *SWS* than material density. Besides, coarse thread screws have lower *SWS* than fine thread screws; namely, the distance between screw threads is also a significant factor. *SWS* from the face was greater than *SWS* from the edge because the face density of MDF is higher than the core density. *SWS* is also affected by the adhesive composition used in particleboard (Farajollah Pour *et al.,* 2022). The reinforcement type in a material increases its *SWS* due to higher density (Perçin and Uzun, 2022). Different size and amount of waste melamine impregnated paper (WMIP) as adhesive in particle boards were studied (Başboğa *et al.,* 2023). *SWS* of particleboard increased with narrower size and higher amount of WMIP.

EP was recommended for frame construction with biscuit joints (Yildirim *et al.,* 2017). EP provides a more durable adhesion with its mechanical adhesion force. It achieves more and faster penetration to the adhesion surface pores on the material than other adhesives due to its higher elasticity (Karaman *et al.,* 2017). Also, an increase in the mechanical interlocking mechanism between wood material and the surface of metal fasteners with EP enhances the *SWS* of wood-based composite materials. In light of this information, the present study was carried out with the idea of adding EP as reinforcement to the screw joint to increase the *SWS* of materials. In doing so, the effects of pilot hole diameters, screw diameter, and amount of EP on *SWS* of MDF and PB from face and edge were investigated.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Design of experiment
2.1. Postavke eksperimenta

In this study, MDF and PB materials, widely used in panel-type furniture and commercially produced, were investigated. A complete four-factor factorial experiment with five replications in each sample group was conducted to determine the *SWS* of the MDF and PB. For this purpose, two materials (MDF and PB), two screw diameters (3.5 mm and 4.5 mm), three pilot-hole diameters (80 %, 90 % and 100 % of screw diameter) and four levels of the EP amount (no-resin, 20 %, 40 % and 60 % of volume of the pilot-hole) factors were selected for edge and face withdrawal from specimens. In doing so, 480 specimens in 96 sample groups were tested to examine the effect of the EP on the *SWS* of the materials.

2.2 Preparation of specimens
2.2. Priprema uzoraka

According to TS EN 13446, all specimens were cut into 50 mm × 50 mm nominal dimensions from 18 mm × 2100 mm × 2800 mm of MDF and PB boards obtained from a local store in the Inegol furniture cluster in Turkey. Table 1 shows the average density and moisture content of the MDF and PB used in the study. The dimensions of the specimens and orientations for the pilot holes are given in Figure 1.a and b. All pilot holes were drilled according to screw diameter and depth of screw penetration in MDF and PB. The depth of the screw penetration is equal to 8d (d: screw diameter) or at most 30 mm for *SWS* from the edge and 16 mm for *SWS* from the face of the materials. Besides, the depth of the pilot hole was 70 % of the depth of the screw penetration.

Table 1 Average density and moisture content of materials
Tablica 1. Prosječna gustoća i sadržaj vode u pločama

Material / *Materijal*	Density / *Gustoća,* g/cm^3						Moisture content, % / *Sadržaj vode, %*		
	Air-dry			Oven-dry					
	Mean	SD*	CoV*	Mean	SD*	CoV*	Mean	SD*	CoV*
MDF	0.70	0.004	0.57 %	0.67	0.004	0.60 %	6.98	0.07	1.01 %
PB	0.62	0.006	0.91 %	0.59	0.006	1.01 %	8.78	0.03	0.30 %

*SD – standard deviation, CoV – coefficient of variation / **SD – standardna devijacija, CoV – koeficijent varijacije*

Table 2 Dimensions of pilot hole and amount of EP for each sample group
Tablica 2. Dimenzije pilot-rupe i količina epoksidne smole za svaku skupinu uzoraka

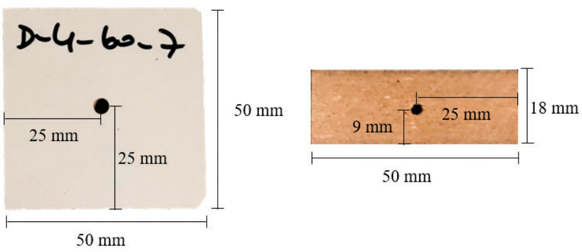
Screw orientations *Orijentacija vijka*	For 3.5 × 45 mm screw (4.5 × 45 mm screw) *Za vijak 3,5 × 45* mm *(vijak 4,5 × 45* mm*)*				
	Depth of pilot hole, mm *Dubina pilot-rupe,* mm	Diameter of pilot hole, mm *Promjer pilot-rupe,* mm	Amount of EP, µl *Količina epoksidne smole,* µl		
			20 %	40 %	60 %
Edge / *rub*	19.60 (21.00)	2.80 (3.60)	26 (50)	50 (100)	75 (150)
		3.15 (4.05)	32 (60)	60 (120)	90 (180)
		3.50 (4.50)	40 (80)	80 (160)	115 (240)
Face / *ploha*	11.20 (11.20)	2.80 (3.60)	20 (32)	40 (65)	60 (100)
		3.15 (4.05)	25 (40)	50 (80)	75 (120)
		3.50 (4.50)	30 (50)	60 (100)	90 (150)

* Values in parathesis are for screws with a diameter of 4.5 mm. / * *Vrijednosti u zagradama odnose se na vijke promjera 4,5 mm.*

Table 3 Length, penetration depth, diameter, and root diameter of screws used in the study
Tablica 3. Duljina, dubina prodiranja, promjer i promjer unutarnjeg navoja vijaka upotrijebljenih u istraživanju

		3.5 × 45 mm screw (4.5 × 45 mm screw) / *Vijak 3,5 × 45 mm (vijak 4,5 × 45 mm)**			
		Length *Duljina*	Penetration depth *Dubina prodiranja*	Diameter *Promjer*	Root diameter *Unutarnji promjer*
Edge *Rub*	Mean	44.14 (44.21)	27.88 (29.24)	3.54 (4.46)	2.33 (2.80)
	SD	0.39 (0.35)	0.73 (0.93)	0.07 (0.04)	0.04 (0.02)
	CoV	0.88 % (0.78 %)	2.61 % (3.19 %)	1.86 % (0.84 %)	1.79 % (0.60 %)
Face *Ploha*	Mean	44.15 (44.19)	15,96 (16.05)	3.53 (4.48)	2.30 (2.80)
	SD	0.40 (0.34)	0.67 (0.69)	0.07 (0.02)	0.02 (0.05)
	CoV	0.90 % (0.76 %)	4.21 % (4.29 %)	2.02 % (0.41 %)	0.78 % (1.78 %)

* Values in parathesis are for screws with a diameter of 4.5 mm. / * *Vrijednosti u zagradama odnose se na vijke promjera 4,5 mm.*



a) b)

Figure 1 Pilot hole position for a) face withdrawal and b) edge withdrawal
Slika 1. Položaj pilot-rupe: a) za izvlačenje iz plohe, b) za izvlačenje iz ruba

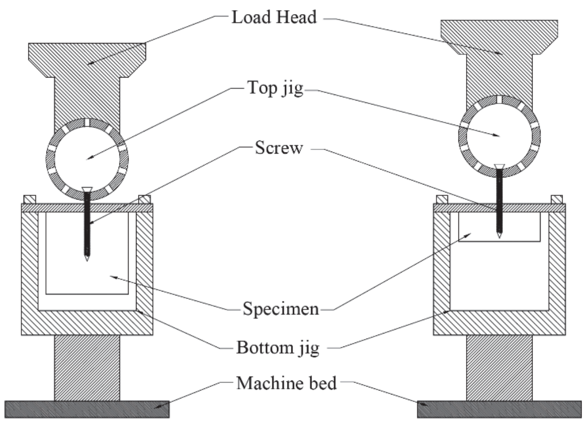
Table 2 shows pilot hole dimensions and the amount of EP for each sample group. Epoxy and hardener, obtained from a local store, were mixed to a 5/2 ratio for 3 minutes. Epoxy and hardener mix were exposed to air for at most 15 minutes before the screws were driven. After each specimen was drilled for a pilot hole and an appropriate amount of EP was injected, 3.5 and 4.5 mm diameter screws were driven into pilot holes to the above length. Table 3 shows the average length, penetration depth, diameter, and root diameter of the screws used in the study.

2.3 Determination of screw withdrawal strength
2.3. Određivanje izvlačne sile vijka

All tests for the *SWS* were conducted on the SHIMADZU universal test machine according to TS EN 13446. Withdrawal loads were obtained by applying a withdrawal load parallel to the screw axis from the edge and face of specimens with a rate of 0.8 mm/min and 2 mm/min, respectively, and continued until the ultimate load was reached (Figure 2). *SWS*, *f* (MPa), was calculated by using Eq. 1.

$$f = \frac{F_{ult}}{d \cdot l_p} \quad (1)$$

F_{ult} – Ultimate withdrawal load (N)
d – Diameter of screw tread (mm)
l_p – depth of screw penetration (mm)



a) b)

Figure 2 Test configuration for a) edge withdrawal and b) face withdrawal
Slika 2. Ispitna konfiguracija: a) za izvlačenje iz plohe, b) za izvlačenje iz ruba

2.4 Statistical analysis
2.4. Statistička analiza

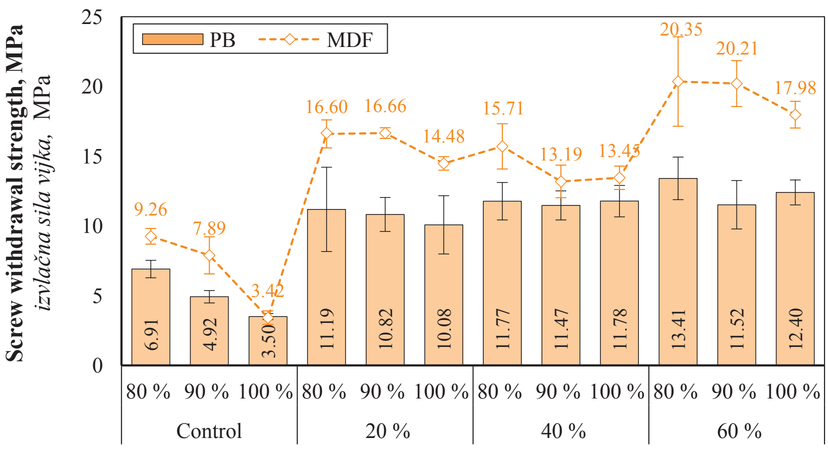
Data collected for all specimens were checked for determining statistical significance through Four-way ANOVA analysis, and Tukey pairwise comparisons were carried out in Minitab Statistical Analysis Software (Minitab Inc. 2013).

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

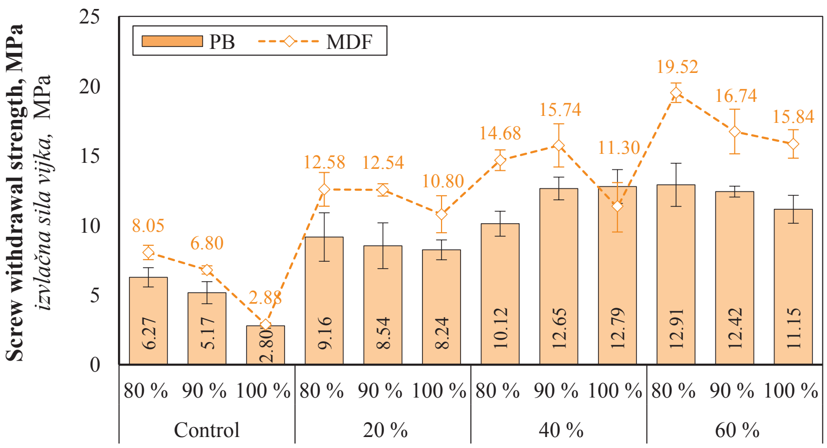
3.1 Screw withdrawal strength from the edge
3.1. Izvlačna sila vijka na rubu

Results for *SWS* from the edge are given in Figure 3. According to test results, the average *SWS* from the edge of MDF was 9.26 MPa with a standard deviation of 0.56 MPa provided that the pilot hole was 80 % of the 3.5 mm screw diameter. An increase in the pilot hole diameter from 80 % to 90 % and 100 % decreased *SWS* of the MDF by 7.89 MPa and 3.42 MPa with standard deviations of 1.32 MPa and 0.47 MPa, respectively. If 4.5 mm diameter screws were used, the average *SWS* from the edge of MDF was 8.05 MPa with a standard deviation of 0.50 MPa, 6.80 MPa with a standard deviation of 0.28 MPa and 2.88 MPa with a standard deviation of 0.13 MPa for 80 %, 90 % and 100 % pilot hole of 4.5 mm-screw-diameter, respectively. If PB was used, the average *SWS* from the edge was 6.91 MPa with a standard deviation of 0.63 MPa, 4.92 MPa with a standard deviation of 0.44 MPa, and 3.50 MPa with a standard deviation of 0.22 MPa for 80 %, 90 % and 100 % pilot hole of 3.5 mm-screw-diameter, respectively. Moreover, those of 4.5 mm-screw diameter had 6.27 MPa with a standard deviation of 0.69 MPa, 5.17 MPa with a standard deviation of 0.78 MPa, and 2.80 MPa with a standard deviation of 0.19 MPa, respectively.

It could be observed that the average *SWS*s from the of MDF are higher than those of PB not only because of internal bond strength but also because the density of the material directly affected the *SWS* (Semple and Smith, 2005; Bal *et al.,* 2017; Jivkov *et al.,* 2017; Başboğa *et al.,* 2023). Besides, statistical analysis results



a)



b)

Figure 3 Effect of amount of EP on *SWS* from edge of material for a) 3.5 mm and b) 4.5 mm screw diameter
Slika 3. Utjecaj količine epoksidne smole na izvlačnu silu vijka na rubu materijala: a) za promjer vijka od 3,5 mm, b) za promjer vijka od 4,5 mm

shown in Table 4 and Table 5 documented that the type of material significantly affected *SWS* from the edge (p-value = 0.000 < 0.05), and that the mean values of *SWS* from the edge of MDF and PB were significantly different from each other (α = 0.05), respectively. Furthermore, larger screw diameter levels yielded decreasing *SWS* values from the edge of both MDF and PB. Although larger screws provide higher *SWS* for materials, screw diameter affected *SWS* when drilling a pilot hole but not the screw insertion technique (Abu and Ahmad, 2015). Therefore, 4.5 mm screw sizes might have an adverse impact on *SWS* because of using EP. The average *SWS* from the edge for a 3.5 mm-screw diameter was 11.3 % higher than those of 4.5 mm. Also, Table 4 and Table 5 showed that screw diameter had a significant impact on the *SWS* from the edge (*p*-value = 0.000 < 0.05) and that the mean values of *SWS* from the edge for 3.5 mm and 4.5 mm screw diameter were significantly different (α = 0.05), respectively.

Pilot hole diameter is vital to the strength of joints with screws because the difference between its shank diameter and screw teeth length affects *SWS* depending on the material. Therefore, it should be close to the shank diameter so that the screw is easily driven into the material without damaging it (Eckelman, 2003). On the other hand, joinery systems with screws allow easily assembled and disassembled furniture construction. However, every effort to disassemble furniture construction enlarges the pilot hole, and re-assembling the furniture results in lower strength of joints. The test results showed that larger pilot hole diameters decreased the *SWS* of materials, while the increased levels of EP injected in the pilot hole enhanced *SWS*. The amount of EP was increased by 20 %, 40 % and 60 % of the pilot hole diameter. In the case of MDF samples with a 3.5 mm screw diameter and 60 % EP, *SWS* from the edge was increased by 119.67 %, 156.56 %, and 425.59 % for 80 %, 90 % and 100 % pilot hole diameters, respectively. Those with 40 % and 20 % EP, increased *SWS* as much as 69.49 %, 67.33 %, 292.66 % and 79.32 %, 111.55 % and 322.94 %, respectively.

Furthermore, *SWS* was increased by 94.24 % when the pilot hole diameter increased from 80 % to 100 %, and the amount of EP increased from 0 to 60 %. *SWS* increase in those with 40 % and 20 % EP was 45.08 % and 56.27 %, respectively. Not only did both the pilot hole (p-value =0.000) diameter and amount of EP (*p*-value = 0.000) have a significant effect on *SWS* from the edge, but the interaction of pilot hole diameter and amount of EP (p-value = 0.000) also significantly affected *SWS* from the edge (Table 4). Furthermore, as shown in Table 5, based on Tukey pairwise comparisons, the mean values of *SWS* from the edge for pilot hole diameter and amount of EP significantly differed at the 95 % confidence level, respectively. An *SWS* increase should be achieved with a screw pilot hole close to the root diameter (Farajollah Pour *et al.,* 2022). The pilot hole diameter should be at least 70 % of the screw diameter (Eckelman, 2003). The holding mechanism of the screw on materials depends on the screw thread rather than the whole screw diameter. In this study, specimens with 70 % pilot hole diameter and EP failed in the case of drilling screws, so these sample groups were omitted from the experiment.

As can be observed in Table 4, interactions of (i) screw diameter and pilot hole diameter, (ii) screw diameter, amount of EP, and material, (iii) screw diameter, amount of EP, and pilot hole diameter, (iv) screw diameter, material, and pilot hole diameter, (v) amount of EP, material, and pilot hole diameter, and (vi) screw diameter, amount of EP, material, and pilot hole diameter had no significant effects on *SWS* from the edge.

3.2 Screw withdrawal strength from the face
3.2. Izvlačna sila vijka na plohi

Test results for *SWS* from the face are given in Figure 4. According to test results, the average *SWS* from the face of MDF was 11.80 MPa with a standard

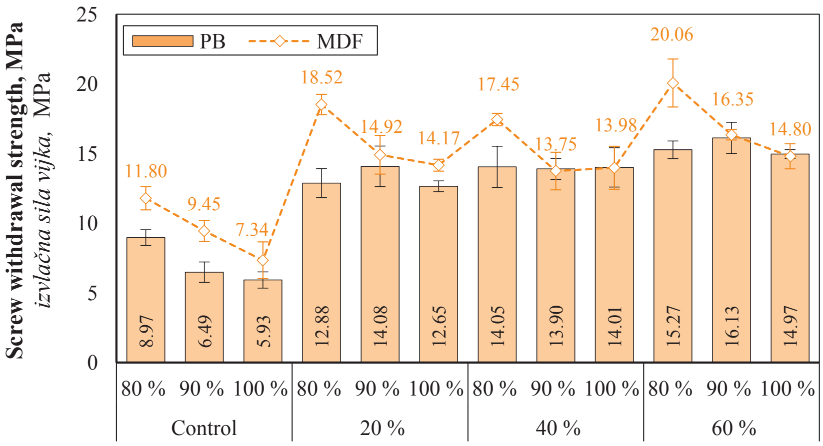
Table 4 Four-way ANOVA for *SWS* from the edge
Tablica 4. Četverosmjerna ANOVA za izvlačnu silu vijka na rubu

Source / *Izvor*	***DF***	**Adj *SS***	**Adj *MS***	***F*-Value**	***P*-Value**
Screw diameter (D) / *promjer vijka (D)*	1	89.59	89.59	50.09	0.000
Epoxy resin (EP) / *epoksidna smola (EP)*	3	3068.02	1022.67	571.79	0.000
Material (M) / *materijal (M)*	1	746.91	746.91	417.61	0.000
Pilot hole (P) / *pilot-rupa (P)*	2	206.88	103.44	57.84	0.000
D*EP	3	73.63	24.54	13.72	0.000
D*M	1	20.85	20.85	11.66	0.001
EP*M	3	199.32	66.44	37.15	0.000
EP*P	6	86.00	14.33	8.01	0.000
M*P	2	55.96	27.98	15.64	0.000
Error	217	388.11	1.79		
Lack-of-Fit	25	88.71	3.35	2.11	0.003
Pure Error	192	304.40	1.59		
Total	239	4935.27			

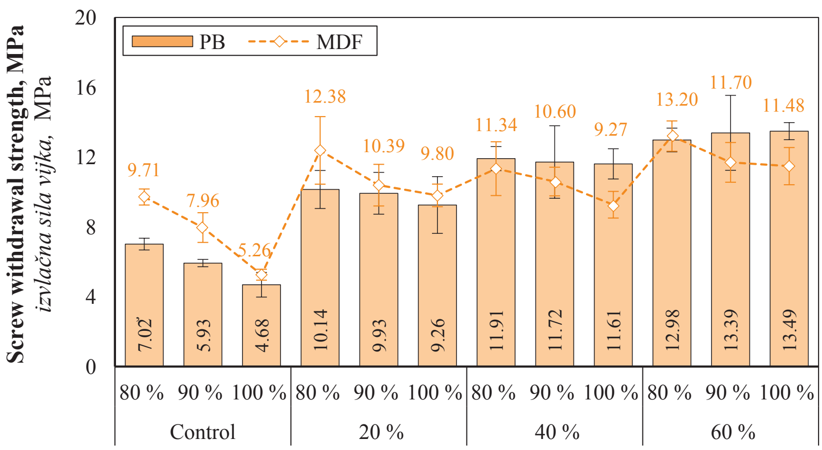
Table 5 Tukey pairwise comparisons for *SWS* from the edge of material
Tablica 5. Tukey usporedbe parova za izvlačnu silu vijka na rubu materijala

Variables / *Varijable*		***N***	**Average** *Prosjek*	**Grouping** / *Grupiranje*			
Material / *materijal*	MDF	120	13.19	A			
	PB	120	9.67		B		
Screw diameter / *promjer vijka*	3.5 mm	120	12.04	A			
	4.5 mm	120	10.82		B		
Amount of EP / *količina epoksidne smole*	60 %	60	15.37	A			
	40 %	60	12.88		B		
	20 %	60	11.81			C	
	Control	60	5.66				D
Pilot hole diameter / *promjer pilot-rupe*	80 %	80	12.41	A			
	90 %	80	11.71		B		
	100 %	80	10.18			C	

deviation of 0.85 MPa if the pilot hole was 80 % of the 3.5 mm screw diameter. Increasing pilot hole diameter from 80 % to 90 % and 100 % decreased *SWS* of the MDF by 9.45 MPa and 7.34 MPa with standard deviations of 0.85 MPa and 0.31 MPa, respectively. If 4.5 mm diameter screws were used, the average *SWS* from the face of MDF was 9.71 MPa with a standard deviation of 0.47 MPa, 7.96 MPa with a standard deviation of 0.85 MPa and 5.26 MPa with a standard deviation of 0.31 MPa for 80 %, 90% and 100 % pilot hole of 4.5 mm-screw-diameter, respectively. If PB was used, the average *SWS*s from the face were 8.97 MPa with a standard deviation of 0.57 MPa, 6.49 MPa with a standard deviation of 0.72 MPa, and 5.93 MPa with a standard deviation of 0.60 MPa for 80 %, 90 % and 100 % pilot hole of 3.5 mm-screw-diameter, respec-



a)



b)

Figure 4 Effect of amount of EP on *SWS* from the face of material for a) 3.5 mm and b) 4.5 mm screw diameter
Slika 4. Utjecaj količine epoksidne smole na izvlačnu silu vijka na plohi materijala: a) za promjer vijka od 3,5 mm, b) za promjer vijka od 4,5 mm

tively. Furthermore, those of 4.5 mm-screw diameters had 7.02 MPa with a standard deviation of 0.35 MPa, 5.93 MPa with a standard deviation of 0.22 MPa, and 4.68 MPa with a standard deviation of 0.69 MPa, respectively.

Four-Way ANOVA results presented in Table 6 showed that all independent variables, namely, screw diameter (p-value = 0.000), material type (p-value = 0.000), amount of EP (p-value = 0.000), and pilot hole diameter, significantly affected the mean values of *SWS* from the face of specimens. In terms of the impact of material type on *SWS* from the face, a similar pattern was obtained with those from the edge; namely, the mean *SWS* from the face of MDF (11.80 MPa) was higher than that of PB (8.97 MPa) because MDF is a denser material with a higher internal bonding strength than PB. Tukey pairwise comparisons identified and documented the presence of *SWS* from the face differences across various levels of each independent factor. Table 7 demonstrated that the mean *SWS* from the face of MDF was significantly different from that of PB (α = 0.05). Table 5 also showed that changing screw diameter levels resulted in significantly different mean *SWS* from the face values. Besides, the mean *SWS* from the face for 3.5 mm and 4.5 mm screw diameters were significantly different from each other (α = 0.05). As given in Table 6, the interaction of screw diameter and material also significantly affected the average *SWS* from the face (p-value = 0.000).

A smaller pilot hole diameter and higher amount of EP resulted in higher mean *SWS* from the face of both MDF and PB. According to Table 6, the interaction of pilot hole diameter and amount of EP (p-value = 0.001) significantly impacted *SWS* from the face. The average *SWS* from the face of MDF increased by 69.94 %, 73.09 %, and 101.28 % for 80 %, 90 % and 100 % pilot hole diameter when using a 3.5 mm screw diameter, and the amount of EP was 60 % of pilot hole diameter, respectively. For the same pilot hole diameters, the increase in *SWS* from the face for the samples with 4.5 mm screw diameter and the amount of EP of 60 % of pilot hole diameter was 68.74 %, 46.85 % and 117.86 %, respectively. Similar increases in the mean *SWS* from the face of MDF and PB were observed for the samples with the amount of EP equal to 20 % and 40 % of the pilot hole diameter. According to Tukey pairwise comparison results, the mean *SWS* from the face for the samples with the amount of EP equal to 60 % of the pilot hole diameter and without resin was significantly different. However, there was not enough statistical evidence to claim that the mean *SWS* from the face values for the groups with an amount of EP equal to 20 % and 40 % of the pilot hole diameter (Table 7) were different. Furthermore, Table 7 also demonstrated that the mean *SWS* from the face values for 80 %, 90 % and 100 % pilot hole diameters were significantly different from each other. Table 6 also showed that interactions of (i) screw diameter, amount of EP, and pilot hole diameter and (ii) all parameters had no significant effects on the *SWS* from the face.

4 CONCLUSIONS
4. ZAKLJUČAK

This study investigated the effect of EP in the pilot hole on the *SWS* of MDF and PB. For this purpose, three pilot hole diameters, four amounts of EP and two screw diameters were investigated.

Internal bond strength and density of material have a significant effect on *SWS*. No matter what pilot

Table 6 Four-way ANOVA for *SWS* from the face
Tablica 6. Četverosmjerna ANOVA za izvlačnu silu vijka na plohi

Source / *Izvor*	***DF***	**Adj *SS***	**Adj *MS***	***F*-Value**	***P*-Value**
Screw diameter (D) / *promjer vijka (D)*	1	613.29	613.29	522.98	0.000
Epoxy resin (EP) / *epoksidna smola (EP)*	3	1602.82	534.27	455.60	0.000
Material (M) / *materijal (M)*	1	61.67	61.67	52.59	0.000
Pilot hole (P) / *pilot-rupa (P)*	2	193.89	96.94	82.67	0.000
D*EP	3	58.40	19.46	16.60	0.000
D*M	1	51.42	51.42	43.84	0.000
D*P	2	10.50	5.25	4.48	0.012
EP*M	3	57.38	19.13	16.31	0.000
EP*P	6	28.09	4.68	3.99	0.001
M*P	2	83.46	41.73	35.59	0.000
D*EP*M	3	10.27	3.43	2.92	0.035
D*M*P	2	10.75	5.37	4.58	0.011
EP*M*P	6	15.95	2.66	2.27	0.039
Error	204	239.23	1.17		
Lack-of-Fit	12	18.22	1.52	1.32	0.210
Pure Error	192	221.01	1.15		
Total	239	3037.11			

Table 7 Tukey pairwise comparisons for *SWS* from the face of material
Tablica 7. Tukey usporedbe parova za izvlačnu silu vijka na plohi materijala

Variables / *Varijable*		*N*	**Average** *Prosjek*	**Grouping** / *Grupiranje*		
Material / *materijal*	MDF	120	12.32	A		
	PB	120	11.31		B	
Screw diameter / *promjer vijka*	3.5 mm	120	13.41	A		
	4.5 mm	120	10.21		B	
Amount of EP / *količina epoksidne smole*	60 %	60	14.48	A		
	40 %	60	12.80		B	
	20 %	60	12.43		B	
	Control	60	7.54			C
Pilot hole diameter / *promjer pilot-rupe*	80 %	80	12.98	A		
	90 %	80	11.67		B	
	100 %	80	10.79			C

hole diameter, amount of EP and screw diameter were used, the *SWS* of MDF was higher than the *SWS* of PB. An increase in screw diameter from 3.5 to 4.5 mm significantly affects the *SWS* of MDF and PB. In the edge and face withdrawal of screws from materials, smaller screw diameter has higher *SWS*. Increase in pilot hole diameter decreases the *SWS* of materials. 80 % pilot hole diameter had greater *SWS* than that of 90 % and 100 % because it was the closest to the root diameter. In addition, an increase in the amount of EP in the pilot hole increases the *SWS* of the material. EP dispenses more and faster in material pores, so it works better after drilling screws in pilot holes. If a piece of furniture with screw-type fasteners were disassembled, its pilot hole would be close to 100 % of or larger than the screw diameter. Using EP in the pilot hole for the following assembly would be beneficial. *SWS* of materials with 80 % pilot hole diameter and no-EP increased by 40 % compared to that of 100 % pilot hole with 60 % EP of the volume of the pilot hole.

The study showed that the existence of EP in the pilot hole increases the *SWS* of both MDF and PB. In this way, it could be used to repair furniture with screw-type fasteners. Moreover, it has a longer life span before being discarded in landfills and increases the reusability and repairability of case furniture to decrease its environmental impacts.

Acknowledgements – Zahvala

This research was funded by the Scientific Research Projects Coordinatorship at Bursa Technical University (Project no: 211N018, 2021).

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