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Withdrawal Resistance of T-Nuts in Various Furniture Materials

Otpor izvlačenju unit-matica iz različitih materijala za namještaj

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ABSTRACT • *T-nuts are factory installed in the holes of the ready-to-assemble furniture components. There is a risk that the t-nut spontaneously falls out during transport or storage and get lost; the t-nut can also be pushed into inaccessible spaces during assembly. These complications can make furniture assembly impossible. For this reason, sufficient force to hold the t-nut in the hole is essential. The article presents the test results of the forces holding the t-nuts in five furniture materials (softwood, Oriented Strand Board, plywood, and particleboard in two variants). The M6 t-nuts with four prongs were installed in predrilled 8 mm holes. The resistance to withdrawal of the t-nuts was measured with a universal testing machine. The tested materials could be divided into three groups in terms of the risk of the t-nut falling out: softwood and plywood – low risk, $F = 1113.2-1158.0$ N; OSB and particleboard – moderate risk, $F = 592.3-645.5$ N, particleboard with a pad – high risk, $F = 645.5$ N. The results show that the withdrawal resistance is not correlated with the density of the wood material, and that it decreased with the degree of wood material processing – the less processed the material, the greater the resistance to withdrawal of the t-nuts.*

KEYWORDS: *T-nut; pinewood; oriented strand board; plywood; particleboard; furniture materials*

SAŽETAK • *Unit-matice tvornički se ugrađuju u provrte dijelova namještaja spremnih za montažu. Postoji opasnost da unit-matice tijekom transporta ispadnu ili da se pri montaži umetnu u pogrešne rupe. Takve situacije mogu zakomplicirati ili onemogućiti sastavljanje namještaja. Stoga je potrebna dovoljna sila da se unit-matica zadrži u provrtu. U članku su prikazani rezultati ispitivanja sila koje drže unit-matice u pet materijala za namještaj (u drvu četinjača, OSB pločama, furnirskim pločama i u dvije varijante iverica). Unit-matice M6 s četiri trna ugrađene su u prethodno izbušene provrte od 8 mm. Otpor njihovu izvlačenju mjereno je univerzalnim uređajem za mehanička ispitivanja. Rezultati su pokazali da se prema riziku od ispadanja unit-matica ispitivani materijali mogu podijeliti u tri skupine: drvo četinjača i furnirska ploča – mali rizik, $F = 1113,2 - 1158,0$ N; OSB ploče i iverice – umjereni rizik, $F = 592,3 - 645,5$ N; iverice s podlogom – visoki rizik, $F = 645,5$ N. Ispitivanja su potvrdila da otpor izvlačenju nije u korelaciji s gustoćom drvnog materijala te da se on sa stupnjem prerade drvnog materijala smanjuje: što je materijal manje prerađen, to je otpor izvlačenju unit-matica veći.*

KLJUČNE RIJEČI: *Unit-matica; borovina; OSB ploča; furnirska ploča; ploča iverica; materijali za namještaj*

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1 INTRODUCTION

1. UVOD

T-nuts with bolts are used to create non-permanent screwed joints between furniture components. Furniture fasteners of this type are commonly used in industrially produced ready-to-assemble furniture. Furniture with t-nuts is simple to assemble with standard fastening tools, offers strong joints, and can be dismantled without furniture damage. During furniture production, the t-nuts are pressed into the drilled holes in the furniture components. The components of furniture with fasteners, as self-assembly kits, are delivered to end customers. The t-nuts are usually made of steel and have a sleeve with internal screw thread and a flange with prongs. The prongs are disposed radially of the flange and prevent the nut from turning while screwing in the bolt (Figure 1).

However, when the furniture is assembled by the end customer, the t-nut can be pushed out of the hole. The t-nuts can also be lost during transport and storage of the ready-to-assemble furniture kits. If it falls into inaccessible spaces or if it cannot be put back into the

hole, then the furniture cannot be assembled, which can be a reason for complaint. Therefore, it is beneficial to ensure a sufficiently high resistance to prevent these t-nuts from falling out of their holes. The force holding the t-nuts in furniture components depends on:

1. T-nut (material, size, design);
2. Technological factors (an engineering fit between the hole and the t-nut sleeve, a force with which the t-nut was pressed into the hole, coaxially of pressing, shape, and quality of the hole in the piece of furniture resulting from the drilling technology);
3. Properties of the furniture component material.

Assuming that the design of the nuts and the technology of their preassembly are appropriate, it was decided to check the effect of the furniture material on the t-nuts withdrawal resistance.

2 MATERIALS AND METHODS

2. MATERIJALI I METODE

Five furniture materials were selected for laboratory testing of t-nuts withdrawal resistance. Twelve samples of each tested material were made (Table 1).

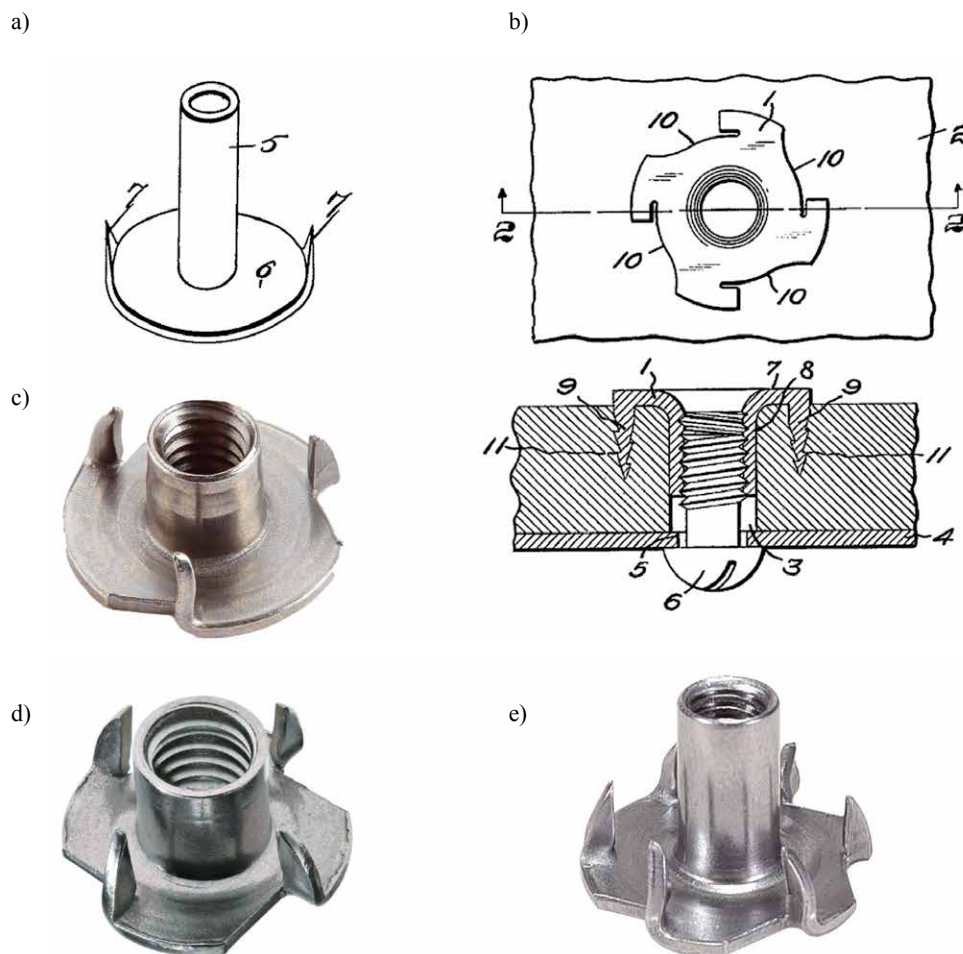


Figure 1 T-nuts: a – according to patent US945737A (Anderson, 1910), b – according to patent US2102558A (Gustav, 1937), c – with three prongs, d – with four prongs, e – with six prongs
Slika 1. Unit-matica: a – prema patentu US945737A (Anderson, 1910.), b – prema patentu US2102558A (Gustav, 1937.), c – s tri trna, d – s četiri trna, e – sa šest trnova

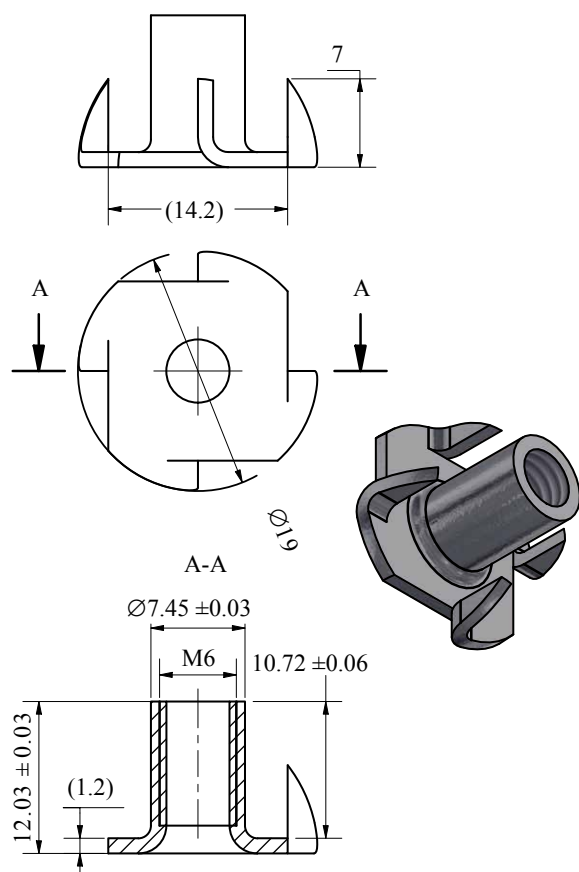


Figure 2 Tested t-nuts with four prongs
Slika 2. Ispitivana unit-matica s četiri trna



Figure 3 Hopper fed t-nut drive machine (Photo: Sigma Tool & Machine)

Slika 3. Stroj za ugradnju unit-matica sa spremnikom

A numerical control processing centre (Skipper 100L, Biesse Group, Pesaro, Italia) and 8 mm fully sharp twist drills for wood with carbide blades were used to drill holes in the tested furniture materials. Woodworking parameters used were as follows: rotation speed 3000 rpm (cutting speed $v_c = 75$ m/min), feed 3.0 m/min (chip load $f_z = 0.5$ mm/tooth). The steel M6 four prongs t-nuts (Figure 2) were placed in the

holes using an industrial hopper-fed t-nut drive machine (model 2598, Sigma Tool & Machine, Toronto, Canada) with a pressure of 0.45 MPa (Figure 3).

The test samples for withdrawal resistance tests are shown in Figure 4. All samples were subjected to a monthly conditioning process ($t = 23 \pm 2$ °C, RH = 50 ± 5 %) that ensured that they have obtained an equilibrium moisture content.

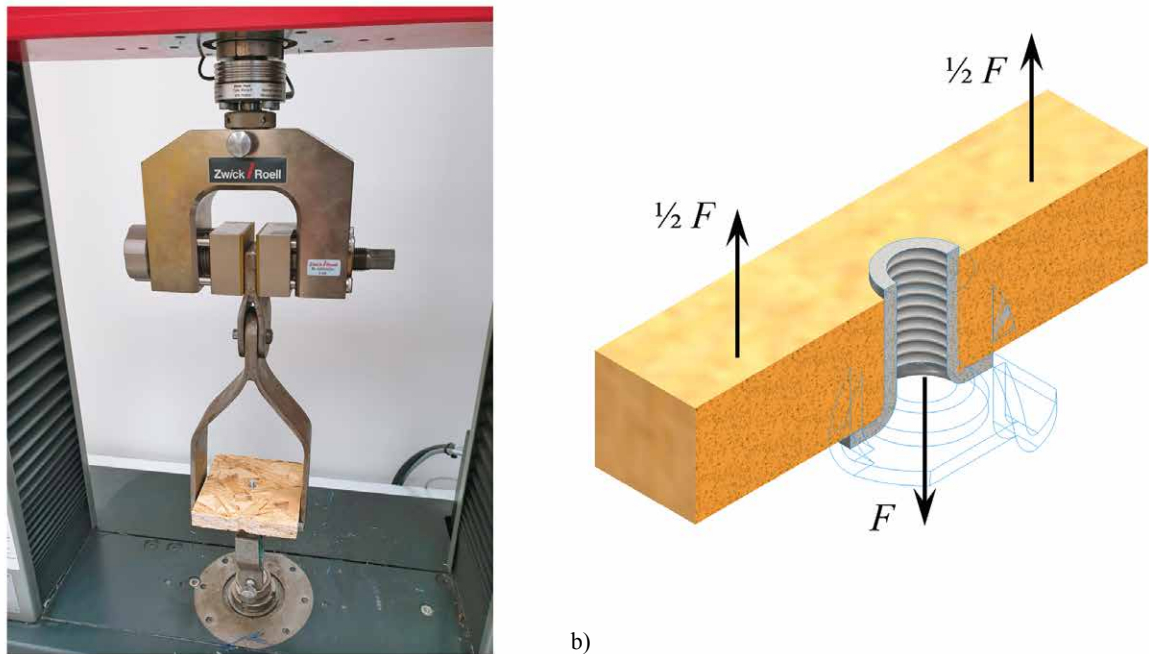
Table 1 Tested furniture materials

Tablica 1. Ispitivani materijali za namještaj

Sample series designation <i>Oznaka serije uzorka</i>	Material <i>Materijal</i>	Dimensions / Dimenzije, mm				Density <i>Gustoća</i> kg/m ³	Number of samples <i>Broj uzoraka</i> <i>n</i>
		Width <i>Širina</i>	Height <i>Visina</i>	Thickness <i>Debljina</i>	Hole diameter <i>Promjer provrta</i> $n = 12,$ $k = 11, \alpha = 095$		
CW_I	Pinewood / borovina <i>(P. sylvestris L.)</i>	20	45	10	7.96 ± 0.04	585.1	12
PW	Plywood (birch-alder, 9-layers) <i>furnirska ploča (breza – joha, 9-slojna)</i>	95	100	15	7.94 ± 0.03	695.3	12
OSB	OSB/1	95	100	15	7.94 ± 0.03	650.1	12
PB_I	Particleboard / ploča iverica	95	100	15	7.97 ± 0.03	717.3	12
PB_II	Particleboard + rubber pad <i>ploča iverica s gumenim podloškom</i>	95	100	15 + 2 (pad)	7.97 ± 0.03	717.3 + 1520.0	12



a) b)
Figure 4 Examples of test samples: a) OSB, b) particleboard with a rubber pad
Slika 4. Primjeri ispitnih uzoraka: a) OSB, b) iverica s gumenim podloškom



a) b)
Figure 5 Withdrawal resistance tests of t-nuts: a) test stand; b) mode of loading the sample with forces
Slika 5. Ispitivanje otpora izvlačenju unit-matica: a) ispitno mjesto, b) način opterećenja uzorka silama

screw screwed into the t-nut. The design of the jig allowed to simulate pulling the t-nut out of the hole in the Group, Ulm, Germany) with the use of a specially made jig consisting of a clamp that holds a wooden element and a screw screwed into a t-nut. The design of the jig allowed to simulate pulling the t-nut out of the hole predrilled in furniture element. The testing device and the method of loading the sample with forces are shown in Figure 5.

The withdrawal resistance tests used the following parameters: initial force 2 N, traverse speed 100 mm/min. The force was measured until the t-nut prongs were fully removed from the wood material.

3 RESULTS 3. REZULTATI

The results of the withdrawal resistance test are the forces that pull the nuts out of the holes. The box plot in Figure 6 shows the locality, variability outside the upper and lower quartiles, means, and median values of these forces for five tested series of furniture materials.

The highest mean pulling out force for t-nuts was observed for softwood, with a similar value but slightly lower for plywood. Lower values of the tearing forces were observed for the OSB board and the particleboard

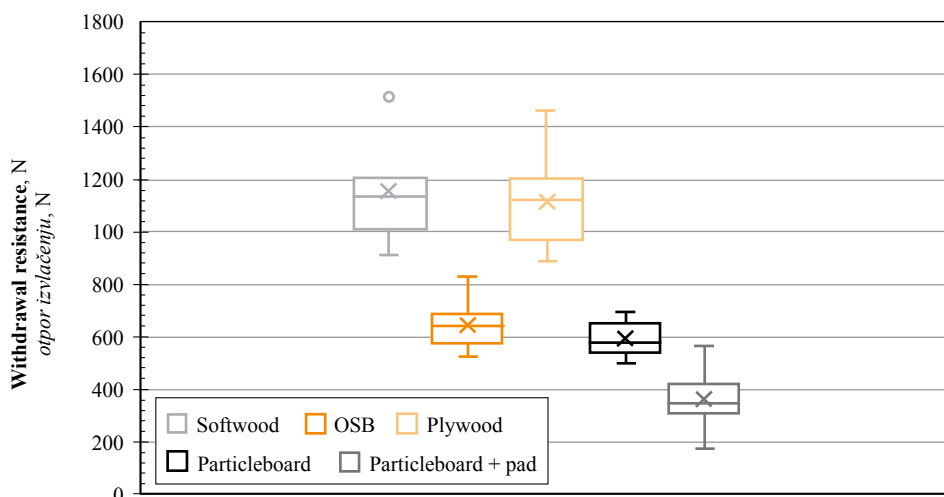


Figure 6 Withdrawal resistance of tested materials ($n = 12$)
Slika 6. Otpor ispitivanih materijala izvlačenju ($n = 12$)

Table 2 Main statistical parameters for tested furniture materials ($n = 12$)

Tablica 2. Glavni statistički parametri ispitivanih materijala za namještaj ($n = 12$)

	Softwood <i>Drvo četinjača</i>	OSB	Plywood <i>Furnirska ploča</i>	Particleboard <i>Ploča iverica</i>	Particleboard + rubber pad <i>Ploča iverica s gumenim podloškom</i>
Mean, N	1158.0	645.5	1113.2	592.3	366.1
SD	198.2	95.1	154.9	63.0	100.3
Minimum, N	913.0	526.1	887.8	500.1	174.9
Median, N	1136.5	640.1	1120.0	577.2	344.4
Maximum, N	1541.0	827.7	1461.0	693.3	561.3
Slant	1.02	0.73	0.68	0.33	0.20
Curtosis	0.41	-0.04	1.19	-0.98	0.83
Shapiro-Wilk (p -value)	0.085	0.360	0.543	0.471	0.898

without a pad. The weakest element was the particle board with a plastic pad. Table 2 summarizes the most important statistical parameters calculated for the five furniture materials tested.

The Shapiro-Wilk normality test of the force value distributions in series was performed. The computed p -values were greater than the significance level $\alpha = 0.05$, so there was no reason to reject the null hypothesis H_0 (the values in the series follow a normal distribution).

Table 3 Summary of all pairwise comparisons for five materials tested (Tukey HSD test)

Tablica 3. Sažetak svih usporedbi u paru za pet ispitivanih materijala (Tukeyjev HSD test)

Samples series <i>Uzorci</i>	Mean pulling force, N <i>Srednja sila izvlačenja, N</i>	Group <i>Skupina</i>		
Softwood / <i>drvo četinjača</i>	1158.0	A		
Plywood / <i>furnirska ploča</i>	1113.2	A		
OSB / <i>ploča s orijentiranim iverjem</i>	645.5		B	
Particleboard / <i>ploča iverica</i>	592.3		B	
Particleboard + pad / <i>ploča iverica s podloškom</i>	366.1			C

Therefore, it was assumed that it was possible to perform a one-way ANOVA. A one-way ANOVA was performed between subjects to compare the influence of five material variants on the pull force value of t-nuts. There was a significant effect of material type on the pulling force at the $p < 0.05$ level for the five variants [$F(4, 55) = 83.14, p = 1,18045E-22$]. Post hoc comparisons using the Tukey HSD test indicated that the softwood samples pulling force values were significantly different from force values of the OSB, particleboard, and particleboard with plastic pad samples. However, the softwood samples did not significantly differ from the plywood samples, and the OSB samples were statistically similar to the particleboard samples. Small differences justify the classification of the five tested materials into three groups, as shown in Table 3.

Taken together, these results suggest the following:

Softwood. Advantageously, a high value of the average t-nut withdrawal resistance ($F_{Mean} = 1158.0$ N), but a very high value of the standard deviation in the sample series ($SD = 198.2$), could indicate a high risk of the nuts falling out of the holes. However, the advantageous feature of this material is a very high value of the minimum withdrawal resistance in the series

($F_{\text{Min}} = 913.0 \text{ N}$), which suggests that the risk of accidentally pushing the nut out of the hole during assembly is the lowest. The softwood standard deviation is the largest among all variants of tested material and is over three times greater than the standard deviation calculated for the particleboard. The explanation for this phenomenon is the large heterogeneity of the structure and thus large diversification of the properties of natural wood compared to other more homogeneous wood-based materials. The high variability of the tensile forces translates into unfavorably variable design properties of the “hole-nut” assembly pair.

OSB. Unfavorably low average t-nut withdrawal resistance ($F_{\text{Mean}} = 645.5 \text{ N}$). However, a moderate value of the standard deviation in the sample series ($SD = 95.1$), although the material appears to have a heterogeneous structure. A small value of the minimum t-nut withdrawal resistance ($F_{\text{Min}} = 526.1 \text{ N}$) indicates a high risk that the t-nuts will spontaneously fall off, which requires counteracting this risk in industrial production (a change in the structure of a furniture element or a technology change).

Plywood. The average t-nut withdrawal resistance is high ($F_{\text{Mean}} = 1113.2 \text{ N}$), similar to the softwood samples. Plywood offers slightly better force values replicability, indicated by a smaller standard deviation than softwood samples ($SD = 154.9$). In terms of the tests performed, plywood is a more homogeneous material than softwood. It also preferably has a high minimum t-nut pulling out force ($F_{\text{Min}} = 887.8 \text{ N}$).

Particleboard (without a pad). The average t-nut withdrawal resistance is small ($F_{\text{Mean}} = 592.3 \text{ N}$), slightly lower than the OSB, while the repeatability of the force values is the highest ($SD = 63.0$). The test results indicate the risk that the t-nuts will fall out spontaneously during customer assembly ($F_{\text{Min}} = 500.1 \text{ N}$), which (as in the OSB) requires counteracting.

Particleboard with a rubber pad. The lowest average t-nut withdrawal resistance ($F_{\text{Mean}} = 366.1 \text{ N}$). Unfavorably large standard deviation in the series ($SD = 100.3$). Very low minimum pulling out force ($F_{\text{Min}} = 174.9 \text{ N}$). The t-nuts withdrawal resistance is the smallest of all tested materials.

4 DISCUSSION

4. RASPRAVA

The assembly of ready-to-assemble furniture is usually performed by a nonspecialist, which imply the need to design furniture that is proof to assembly errors with uncomplicated fasteners (Branowski *et al.*, 2020). Few studies describe the load capacity of t-nuts in wood materials. In Eckelmann's studies, the loading force direction was the opposite of the direction used in our studies. The t-nuts were pulled

through holes made in various types of wood materials, and the load capacity of the t-nuts joints was measured. The goal was to measure the value of the forces that break the screwed joint. The t-nuts in high-density wood are damaged due to the separation of the sleeve from the flange. The t-nut can be fully pulled through the hole in a less dense wood, locally damaging the surrounding wood. The ability of t-nuts to transfer forces is mainly related to the outer diameter and thickness of the t-nut flange. The properties of the wood material are another essential factor. The harder the wood material, the larger the t-nut flange diameter, and the greater the flange thickness – the stronger the joint (Eckelman, 1998).

Our research aimed to check the resistance of t-nuts to pull out of the five furniture materials (the t-nut withdrawal resistance). The t-nut anchoring mechanism in a fastened element is similar to that of nails. The t-nut prongs, nailed into the element, resist withdrawing through frictional forces like smooth shank nails. The nail-type anchoring mechanism of the prongs justifies comparing our test results with literature reports on the holding force of axially withdrawn nails. Similar to the work of (Chow *et al.*, 1988), our study shows that the t-nut withdrawal strength in plywood is greater than in OSB. Reports in the literature that describe the withdrawal resistance to nail removal in various wood species and wood-based materials indicate that the higher the density of the wood material – the greater the resistance (Rammer and Zelinka, 2015; Ringhofer *et al.*, 2018). The results of our research do not show such a relationship. This suggests that the friction coefficient between the prongs and the material of the furniture may be decisive in this case. Additional data collection would help to confirm this statement.

The t-nut withdrawal resistance in our research seems to depend on the degree of processing of the furniture material. The more processed the material, the less the t-nut withdrawal resistance. Chaharmahali *et al.*, 2008 stated that the greater the differentiation of properties of the phases in the wood composite, the lower the force holding the nails. Our results show the dependence between t-nut withdrawal resistance and degree of wood material processing. The t-nut withdrawal resistance decreases with an increasing degree of material processing. It is the smallest for particleboard, increasing in value for OSB and plywood, and it is the largest for softwood.

5 CONCLUSIONS

5. ZAKLJUČAK

The results of this study suggest the following:

1. In the case of mounting t-nuts in holes made in various wood-based materials, obtaining the highest

minimum force in the “nut-hole” assembly pair is crucial – it is even more important than obtaining a small dispersion of holding force values (low standard deviation in series). The minimum force holding the nuts in the holes determines the risk of inability to assemble the furniture.

2. The tested furniture materials can be divided into three groups: A (softwood, plywood) – high t-nuts withdrawal resistance, unfavorably large dispersion of this force value, but a low risk of the nut falling out due to the high value of the minimum force required to pull the nut out B (OSB, particleboard) – moderate minimum force, moderate dispersion of results, required and potentially possible improvement actions; C (particleboard with pad) – low minimum force and therefore a high risk of the nut falling out. The moderate value of the standard deviation (quite good repeatability of the results in the series) is a reasonable justification for undertaking an attempt to increase the average force holding the nuts in OSB and particleboard.
3. The test results show that the forces holding the nuts in the holes decrease with the increased degree of processing of wood materials.

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