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Diagonal Tension Performance of Impregnated Woodworking Corner Joints

Svojstva dijagonalnog naprezanja impregniranih kutnih spojeva od drva

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ABSTRACT • *In this study, the effects were examined of wood species, processing types and processing time on diagonal tension performance of woodworking corner joint with double tenon and mortise. Test samples were prepared by using Scots pine (<u>Pinus sylvestris</u> Lipsky), sessile oak (<u>Quercus petreae</u> Lipsky) and black locust (<u>Robinia pseudoacacia</u> L.). Poly vinyl acetate (PVAc) adhesive was used to join the tenon and mortise corner joints. The samples were impregnated by using the method of immersion for 20 and 40 min with a mixture of wax / linseed oil (3 % paraffin, 10 % linseed oil, 87 % white spirit) and Imersol-Aqua. The test of diagonal compression was used to test 120 samples. In this study, the minimum strength decrease of around 68 % was obtained for Scots pine impregnated with Imersol-Aqua for 40 min and the highest strength increase of around 10 % was obtained for sessile oak samples impregnated with Imersol-Aqua for 40 min. The highest diagonal tension performance of 879.734 N·m was obtained for oak samples impregnated with Imersol-Aqua for 40 min., the lowest diagonal tension performance of 189.111 N·m was obtained for Scots pine samples impregnated with Imersol-Aqua for 40 min.*

KEYWORDS: *paraffin; linseed oil; Imersol-Aqua; diagonal tension; woodworking corner joints*

SAŽETAK • *U radu je prikazano istraživanje utjecaja vrste drva te postupka i vremena njegove obrade na dijagonalno naprezanje kutnog spoja od drva s dvostrukim čepom i rupom. Uzorci su pripremljeni od drva bora (<u>Pinus sylvestris</u> Lipsky), drva hrasta kitnjaka (<u>Quercus petreae</u> Lipsky) i drva bagrema (<u>Robinia pseudoacacia</u> L.). Za lijepljenje spojeva upotrijebljeno je polivinilacetatno ljepilo (PVAc). Uzorci su impregnirani 20-minutnim i 40-minutnim uranjanjem u smjesu voska i lanenog ulja (3 % parafina, 10 % lanenog ulja, 87 % white spirita) te u Imersol-Aqua. Na 120 uzoraka provedeno je tlačno ispitivanje u dijagonalnom smjeru. Istraživanjem je utvrđeno najmanje smanjenje čvrstoće (od oko 68 %) na borovini impregniranoj u Imersol-Aqua u trajanju 40 minuta, a najveće povećanje čvrstoće (oko 10 %) postignuto je na uzorcima drva hrasta kitnjaka impregniranima 40 minuta u Imersol-Aqua. Najveće dijagonalno naprezanje od 879,734 N·m izmjereno je na uzorcima hrastovine impregniranima 40 minuta u Imersol-Aqua, a najniže dijagonalno naprezanje od 189,111 N·m ustanovljeno je na uzorcima borovine impregniranima 40 minuta u Imersol-Aqua.*

KLJUČNE RIJEČI: *parafin; laneno ulje; Imersol-Aqua; dijagonalno naprezanje; kutni spojevi od drva*

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1 INTRODUCTION
1. UVOD

Wood has many good qualities, including its thermal properties, high resistance, easy processing, and ability to accept paint and varnish and to absorb sound. It creates a warm and pleasant atmosphere where it is used aesthetically, which makes it a popular material to use both naturally and with the necessary preservatives. Wood is used intensively as auxiliary material with other building materials in addition to its individual use in all kinds of outdoor conditions. Therefore, applications for turning wood into a durable material by using it in suitable conditions have gained traction. However, wood is a hygroscopic, anisotropic biopolymer, mainly formed by cellulose, hemicellulose, and lignin (Yang *et al.,* 2019; Wang *et al*., 2014). In such products, leaving the material unprotected against the effects of open-air leads to defects, such as loss of color, caused by factors such as sunlight (UV rays), rain, wetting and drying, fiber loss due to cracks, and the gradual erosion of the damaged surface. It is important to reduce these negative effects by rationally using the appropriate wood species under suitable outdoor conditions, extending the life of the wood material with appropriate impregnation methods, and applying top surface treatments. Extending the life of the wood material might help meet the country's needs and provide foreign currency input by exporting these wood materials. Removing water from wood with water repellent treatments is one of the methods to extend the life of wood.

Water repellent treatments could increase water repellency and dimensional stability of wood, as well as reduce wood checking increased by outdoor weathering. Paraffin wax is the most common water repellent applied in the wood industry (Schultzet *et al.,* 2007). The paraffin wax deposited in wood capillaries can reduce water penetration by capillary action, thus limiting dimensional swelling (Evans *et al*., 2009). However, the failure of protection is associated with the nonbond between the cell wall and deposits (Humar *et al*., 2013). A super hydrophobic surface provided by microstructure could resist the contact between water and the wood surface (Wang *et al*., 2011). The waterproof effect relies entirely on the fabrication of the structure on the wood surface, but this microstructure might be damaged when exposed to environmental weathering. Furthermore, the hygroscopicity can be minimized by the decreased or covered hydroxy achieved via chemical modification of wood, such as acetylation, esterification, furfurylation, and so on. However, the most commonly used impregnations contain inorganic toxic substances in chemical modification, such as copper, chromium, arsenic, and their compounds. Currently, increasing cases of cancer and negative environmental effects have spurned a push for organic wood preservatives that will not negatively affect the environment and health, while the chemical modifications might be environmentally unfriendly (Pilgård *et al*., 2010). It is well-known that there is an increasing need for green and renewable materials, such as waxes and oils, derived from plants (He *et al*., 2019- Chen *et al*., 2020).

One of these preservatives is linseed oil. Linseed oil, traditionally used as a surface coating, is a natural, organic chemical that can be used as a wood preservative. It can penetrate the cell walls well enough during the impregnation process, reduce hygroscopic movements in the wood, act as a stabilizer, and since it is considered hydrophobic, it is regarded as a unique chemical. At the same time, during impregnation, linseed oil fills gaps such as tracheid lumens, rays, and cracks caused by the drying process (Olsson *et al.*, 2001).

The effects of bio-oil and epoxidized linseed oil on water absorption, tangential swelling, decay and insect resistance, thermo-gravimetric analysis, and mechanical properties of treated wood samples were studied and it was reported that, in terms of wood strength, the impregnated bio-oil generally reduced the mechanical properties of wood except for modulus of elasticity (Temiz *et al*., 2013).

The strength of Scots pine, fir, chestnut and flat tongued, smooth-tongued dowel, secret tongue, hidden tongue-dowel corner joints, manufactured by Taurus cedar, against the tensile forces was examined and the highest tensile strength was obtained on joints with smooth and grooved pine material in the merge, while the lowest tensile strength was obtained on chestnut material in the flat-tongued merge (Tokgöz *et al.*, 2005).

According to the test results of the diagonal tension performance based on PVAc glue assembly with 2nd Class poplar, chestnut and pine timber, which are widely used in house interiors and door joinery works, the best tensile strength was obtained by pine timber (1.1009 N/mm^2), then chestnut (0.5467 N/mm^2) and poplar (0.5620 N/mm^2) timber. It was reported that the values of chestnut and poplar timber diagonal tensile strength are statistically significant (Gökdemir and Yıldız, 2001).

In their study, Tokgöz and Uzer (2007) used three different types of barefaced corner joints, three different species of wood (Scotch pine, chestnut, fir), and polyvinyl acetate (PVAc) glue in their assembly. As a result of the pressure and tensile tests, Scotch pine was observed to be the strongest material, the best tensile strength in terms of the joint could be obtained with a concealed barefaced tenon, and there was no significant difference between the joints in terms of compressive strength. In his study, User examined the diagonal compressive and tension performance by combining three different wood species (Scots pine, chestnut, fir) of specific humidity level (u = 12 %) with a slip corner joint, haunched stub tenon corner joint and diagonal haunched stub tenon corner joint. The resulting construction showed that the highest diagonal tensile strength was obtained with haunched stub tenon corner joint (Scotch Pine: 73.5 kg/cm^2, chestnut: 64 kg/cm^2, fir: 42.5 kg/cm^2), followed by diagonal haunched stub tenon corner joint (Scotch Pine: 64.5 kg/cm^2, chestnut: 57.5 kg/cm^2, fir: 38 kg/cm^2) and the least with slip corner joint (Scotch Pine: 59 kg/cm^2, chestnut: 52.5 kg/cm^2, fir: 35.5 kg/cm^2). The highest diagonal compressive strength was obtained with diagonal haunched stub tenon corner joint (Scotch pine: 73.5 kg/cm^2, chestnut: 64 kg/cm^2, fir: 42.5 kg/cm^2), followed by slip tenon corner joint (Scotch pine: 64.5 kg/cm^2, chestnut: 57.5 kg/cm^2, fir: 38 kg/cm^2) and the least with haunched stub tenon corner joint (Scotch pine: 59 kg/cm^2, chestnut: 52.5 kg/cm^2, fir: 35.5 kg/cm^2) (Uzer, 1999).

In a study on "The effects of tree species, pressing direction and glue type on diagonal direction (diagonal) pull performance in single-and double-tongued wooden chopping wood type corner joints", diagonal tension performance was obtained on double-tongued Scots pine samples that were glued with PVAc-D_4 glue. On the other hand, the lowest diagonal tensile strength was reported on single-tongued fir samples that were glued with PVAc glue (Altınok *et al.*, 2009).

Laminate test samples, obtained by pasting oak, chestnut, beech and pine veneers with resorcinol formaldehyde, melamine formaldehyde, PVAc-D_4 and VTKA glue, were impregnated with paraffin solution of 3 % concentration (3 % paraffin, 10 % linseed oil, 87 % white spirit). The prepared experimental samples were exposed to outdoor weather conditions for a year and the performance of impregnation process against the atmosphere was investigated (Doruk, 2009).

In the study of Altınok *et al*. (2016), Scots pine and chestnut woods were glued with polyurethane based vinyl tree ketonol acetate (VTKA) and Polyvinyl PVAc-D_4, and double-tongued wood joinery was made. Impregnation was carried out with a 5 % solution of tannin and oak with a natural pine cone resin. Samples were kept for one year in outdoor conditions, diagonal test was performed and it was reported that the natural form treated and untreated samples and comparison of window wings holding the external environment gained strength during the degradation and the reasons for this deterioration were detected against the impregnated material.

In the study of Arslan *et al*. (2006), in which the tensile strength and sag values of the tongued joints applied on wooden window sashes were investigated, those with dowel joints were found to give better results than those without dowel joints in terms of tensile strength and sag data in lower and upper tongued joints of wooden window sashes.

To examine the effects of wood species and impregnation (procedure types and process time) in performance of window frames corner joint with double tenon, "L corner joint" type samples (in total 120) were manufactured by using Scots pine, oak and black locust. PVAc-D_4 adhesive was used to bond tenon and mortise corner joints. The samples were impregnated by using the method of immersion for 20 and 40 min with a mixture of wax and linseed oil (3 % paraffin, 10 % linseed oil, 87 % white spirit) and Imersol Aqua. The diagonal compression test was applied to test samples (to determine performance of the window frames corner joint) according to ASTM-D 143-83 1983 standards. Finally, the highest diagonal compression performance was obtained on black locust samples (7480.016 N) impregnated with Imersol Aqua for 40 min. The lowest diagonal compression performance was observed on oak samples (2572.706 N), which were impregnated for 40 min with a mixture of wax / linseed oil (Altınok *et al*., 2013).

In their study, Onduran *et al*. (2017) investigated the effects of wood modification (thermo-processing and impregnation) and outdoor conditions of storage (natural aging) on the mechanical performance of industrial woodwork. For this purpose, Scots pine (*Pinus sylvestris* L.) and chestnut (*Castanea sativa* Mill) wood were used. Experimental examples were applied in actual size. The samples were prepared using the double tenon-mortise corner joints, commonly used in construction, and polyurethane based VTKA and PVAc-D_4 as glue. Diagonal woodwork test samples were prepared by Thermo S class (185 °C temperature with a thermo-vapor process protection). After applying the heat treatment, the test samples were impregnated with a solution of 95 % natural pine cone resin and 5 % pine tannin by dip method (2 hours). Then, the untreated samples (control), only heat-treated samples and heat treated + impregnated samples were kept for 1 year in outdoor conditions (aging). At the end of the aging process, the samples were tested and it was reported that the performance of woodwork was lower after aging in untreated and heat treated pieces. On the other hand, after aging - heat treated + impregnated materials increased the values. The deformation value of woodwork increased after aging in most untreated materials, while heat treated and heat treated-impregnated materials reduced the effects of aging.

When wood material was left unprotected, it could be easily damaged under the corrosive effect of the external environment. This creates irreparable damages or can only be repaired at high costs. It became a necessity to protect wood with various materials in order to prevent the deterioration of unprotected wood.

In this study, after preparing the double-tongued Scotch pine, white oak and black locust wood chopping half frame (corner) samples were impregnated with Imersol-Aqua and a mixture of paraffin-linseed oil-spirit according to 20 and 40-minutes immersion method.

Practitioners stated that dip impregnation subsequently applied in gluing completed wood works corner joint samples would result in decay of glue joints. Therefore, it was aimed to determine the diagonal tension performance of these prepared samples.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Scotch pine (*Pinus sylvestris* L.), sessile oak (*Quercus petrea* L.) and black locust (*Robinia pseudoacacia* L.) wood species were used in the experiments. Wood materials were obtained by the method of random selection from the site of Ankara Furnishers. Wood materials of natural color, free of insect and fungi damage, clean, free of decay, without growth defects, smooth parallel to grain and part of the sapwood were ensured. Some of the technical characteristics of wood species used in the experiment are given in Table 1.

2.1 Impregnation process
2.2. Postupak impregnacije

As impregnation material, Imersol-Aqua and paraffin linseed oil with the melting point of 56 °C, as organic solvent, colorless (white) spirit was used. Paraffin solution of 3 % on the weight basis (3 % paraffin, 10 % linseed oil, 87 % colorless spirit) was prepared (Yıldız and Hafızoğlu, 1990). Imersol-Aqua (I-A), used in the impregnation process, was supplied by HEMEL (Hemel Hicson Timber Product Ltd.), Istanbul, Turkey. I-A is available on the market in the form of odorless, non-flammable, light straw color, water-based solvent having a pH of 7 and a density of 1.03 g/cm^3; it is entirely soluble in water and does not create corrosion on the metal surfaces. I-A contains 0.5 % w/w tebuconazole, 0.5 % w/w propiconazole, 0.1 % w/w 3-iodo-2-propynyl-butyl carbamate, 0.5 % w/w cypermethrin, etc. (Örs *et al*., 2003).

After dipping in Imersol-Aqua and paraffin solution, the test samples were impregnated by being kept in the solution for 20 and 40 minutes. At the end of each period, the surfaces of samples were removed from the solution and dried. The impregnated samples were kept in air-conditioning fridge at the temperature of (20±2) °C and relative humidity of (65±5) % until reaching moisture balance (Voulgaridis, 1986). Impregnated samples, the retention rate of which was to be determined, were dried in the oven at 55 °C until they reached constant weight, cooled in desiccator and weighed. Thus, the amount of net impregnation of each sample, whose exact dry weight was determined after impregnation, was calculated from Eq. 1.

$$ANI = ((M_s - M_o)/M_o) \times 100 \quad (1)$$

Where:
ANI - Amount of Net Impregnation (%)
M_s - exact dry weight after impregnation (g)
M_o - exact dry weight before impregnation (g)

2.2 Glue
2.2. Ljepilo

Polyvinyl acetate PVAc-D$_3$ (single component) and polyvinyl acetate PVAc-D$_4$ (two-component), which was strengthened by adding 5 % hardener (Turbo hardener 303.5), were used for gluing the experimental samples. PVAc-D$_3$ glue is marketed as single component according to BS EN 204 (BS EN 1991) and as ready for use for D$_3$ class of service. In practice, it is applied on the surface as follows: 120-180 g/m². The

Table 1 Some technical characteristics of wood species used in the experiment (Bozkurt, 1987)
Tablica 1. Neka tehnička svojstva vrsta drva obuhvaćenih istraživanjem (Bozkurt, 1987.)

Wood species *Vrsta drva*	**Density (*MC*=0 %)** *Gustoća (MC=0 %)* g/cm^3	**Density (*MC*=12 %)** *Gustoća (MC=12 %)* g/cm^3	**Bending strength (*MC*=12 %)** *Čvrstoća na savijanje (MC=12 %)* kg/cm^2	**Compression strength parallel to grain (*MC*=12 %)** *Čvrstoća na tlak paralelno s vlakancima drva (MC=12 %)* kg/cm^2
Scotch pine *borovina*	0.496	0.52	648.7	379.2
Sessile oak *drvo hrasta kitnjaka*	0.675	0.69	1185.0	606
Black locust *drvo bagrema*	0.720	0.76	1361	730

open standby time for 20 °C is 10 minutes (Anonim, 2009). According to BS EN 204, PVAc- D_4 can be aligned with the pasting quality of D_4 by increasing the moisture durability by adding 5 % hardener to the PVAc-D_3 glue solution (Söğütlü and Döngel, 2007).

2.3 Preparation of test samples
2.3. Priprema ispitnih uzoraka

In this study, wood species (3), impregnation types (2), impregnation time (2) and a total of 120 (3x2x2x10) samples, 10 of which were used in each sample, and diagonal tension performance test samples (with slip corner joint) were prepared (Figure 1). So, these tests were repeated ten times for each sample and their averages were used for the analysis.

Sample sizes, cut from rough drafts, were dried naturally in ventilated conditions and away from direct sunlight by putting fir slats in between. After that, they were kept in air-conditioning fridge at the temperature of (20±2) °C and relative humidity of (65±5) % until they reached 12 % humidity equilibrium. After discontinuing the sample stubs, that have reached equilibrium humidity, of the net size, mortise and equivalents were opened at the ends of the components in the milling machine. Afterwards, the mortises were pressed by applying 160 g/m^2 of glue. Pressed samples were held until their glue combinations were fully hardened (4 weeks). The pressure is applied to the tenon surface of test samples according to industrial applications and in the same amount (about 2 N/mm^2) (Selbo, 1975). Equal pressure was tried to be achieved by making equal number of rotations for each sample after taking compression gap hooks by using compression lugs during the application of pressure. Impregnation was applied to prepare tensile test specimens as described above.

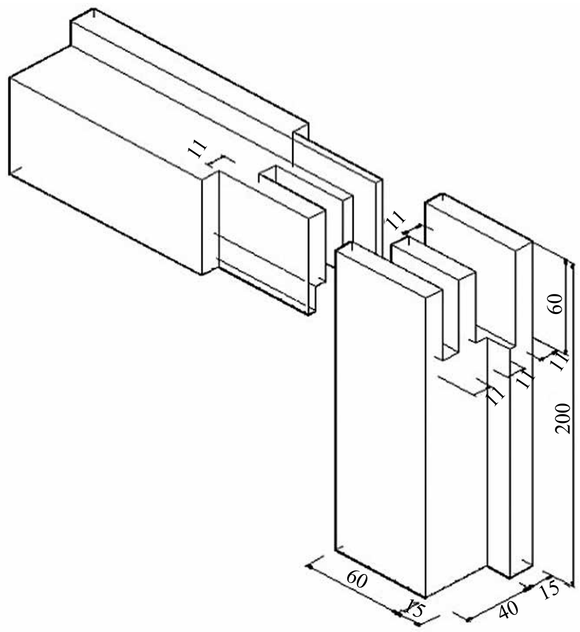

Figure 1 Diagonal tension performance test sample (dimensions in mm)
Slika 1. Izgled uzorka za ispitivanje dijagonalnog naprezanja (dimenzije u mm)

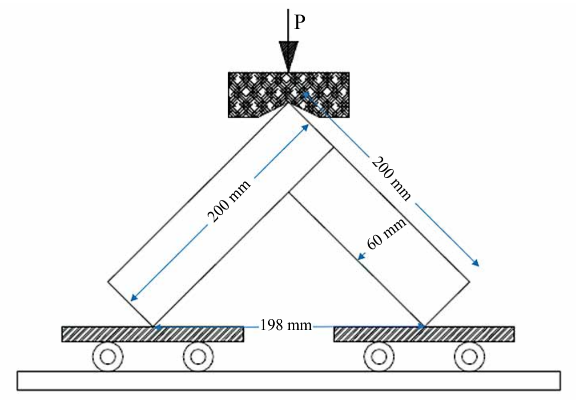

Figure 2 Diagonal tension performance test
Slika 2. Dijagonalno tlačno ispitivanje

2.4 Diagonal compression performance on L-Type samples
2.4. Dijagonalno tlačenje L-uzoraka

The diagonal compression test experiments and deformation value of woodwork examples were held according to the ASTM 1037 standard, in 800 Kp stage of Universal Testing Machine with a capacity of 5 tons. The experimental device was set to increase the compression with a speed of 2 mm/min^1. The maximum force, read from the machine, was recorded in the unit (Figure 2). The maximum force, read from the machine, was recorded in N.

In the diagonal tensile test, the moment (M_{dt}) inserted to corner is calculated by Eq. 2 (Figure 2):

$$M_{dt} = 0.5 \cdot P_{maxTn} \cdot Lx \text{ (N·m)} \quad (2)$$

Where:
M_{dt} - moment of inertia (N·m),
P_{maxTn} - maximum force at the moment of displacement (N),
Lx - torque distance (198/2= 99 mm).

2.4 Data analysis
2.4. Analiza podataka

Multiple analysis of variance was made in wood chopping corner joints in order to determine the effects of wood species, impregnation type and impregnation period. In case of mutual interactions of sources of variance, significant at α = 0.05, Duncan test was used to identify which factors made the difference.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Table 2 shows the amount of impregnation (retention rates) of test samples, which was recorded by using the immersion method of 20 and 40 minutes.

Table 2 Amount of net impregnation obtained from test samples (%)
Tablica 2. Količina neto impregnacije dobivene iz ispitnih uzoraka (%)

	Scots pine / *Borovina*		**Black locust** / *Drvo bagrema*		**Sessile oak** / *Drvo hrasta kitnjaka*	
	Imersol-Aqua	Paraffin linseed oil *Parafinsko laneno ulje*	Imersol-Aqua	Paraffin linseed oil *Parafinsko laneno ulje*	Imersol-Aqua	Paraffin linseed oil *Parafinsko laneno ulje*
20 min	0.402	0.372	0.730	0.723	0.614	0.610
40 min	0.406	0.402	0.742	0.751	0.651	0.657
Increase / *Povećanje*	0.004	0.03	0.012	0.028	0.037	0.047

Observing the amount of net impregnation obtained from test samples, a little increase was seen in the amount of impregnation within the experimental samples. However, this increase in retention rate was very low, around 1 % in all wood species and impregnation articles (40 min). As in other studies, in order to reduce the water or moisture intake of wood material obtained from Beech, Alder, Spruce and Scotch Pine tree species, Var (2001) impregnated the samples by immersing them in impregnation solution (3 % paraffin wax / 10 % linseed oil / 87 % white spirit) for a duration of 1/3, 3 and 24 hours and reported that the amount of retention increased with the immersion time.

Oriental beech, European oak, Scots pine, Uludag fir, Oriental spruce and Lombardy poplar wood samples were prepared and impregnated with Imersol-Aqua, commonly being used in construction wood materials by the method of short, medium and long-term of dipping, and different amounts of retention were found depending on wood species and impregnation period. Retention is the highest in beech and lowest in pine. Retention was found higher in hard woods than soft woods. As the period of dipping increased, retention increased and the highest was found in long-term dipping, as reported by Keskin *et al*. (2008).

Statistical averages of diagonal tension performance in terms of wood species, process type and processing time are given in Table 3.

In this case, differences have been found to occur between the values obtained by the variation of wood species, process type and processing time on diagonal tension performance of chopping at corner joints and that of control samples.

By applying multiple variance analysis of the averages of diagonal tension performance obtained from variation of wood species, process type and processing time on diagonal tension performance of chopping at corner joints, results are given in Table 4.

According to the results of variance analysis, it can be seen that values in terms of diagonal tension performance of wood species, process type, processing time, and their binary and triple comparisons are different at $\alpha = 0.01$ significance level. Accordingly, this difference can be considered important in terms of level of importance. Duncan test of multiple comparison tests at $\alpha = 0.05$ significance level was applied in order to determine the differences between these groups. The results of binary comparison done in terms of wood species, processing time and process type that were thought significant are given in Table 5. According to the results, the performance of sessile oak was 59 % better than that of Scots pine, and 36 % better than that of black locust. In general, the results showed poor performance of both impregnating agents because gluing was applied before impregnation. The reason of lower diagonal tension performance of samples that were impregnated with paraffin linseed oil is possibly the result of the liquid solvent (spirit) that reduces the bonding strength by decomposing the glue line. Additionally, the mechanical resistance of the linseed oil showed a 75 % and 105 % weight gain decrease, and microstructural changes were reported to occur. Cracks in the tracheid cell wall were observed in these loadings. This was the result of the increase in the internal pressure in the cell wall due to the application of the mechanical oil loading. This pressure leads to micro-cracks in the

Table 3 Statistical averages of diagonal tension performance based on wood species, process type and processing time (N·m)
Tablica 3. Statistički prosjeci dijagonalnog naprezanja s obzirom na vrstu drva te na vrstu i trajanje obrade (N·m)

	Scots pine / *Borovina*		**Black locust** / *Drvo bagrema*		**Sessile oak** / *Drvo hrasta kitnjaka*	
	Imersol-Aqua	Paraffin linseed oil *Parafinsko laneno ulje*	Imersol-Aqua	Paraffin linseed oil *Parafinsko laneno ulje*	Imersol-Aqua	Paraffin linseed oil *Parafinsko laneno ulje*
20 min	696.059	534.713	446.274	244.049	739.065	837.795
40 min	461.807	387.347	189.111	461.224	879.734	808.768
Control *Kontrolni uzorci*	862.465		592.548		798.114	

Table 4 Variance analysis of diagonal tension performance (N·m)
Tablica 4. Analiza varijanci dijagonalnog naprezanja (N·m)

Source of variance *Izvor varijance*	**Sum of squares** *Zbroj kvadrata*	***SD***	**Average of squares** *Prosjek kvadrata*	**Value of *F*** *Vrijednost F*	***P* ≤ 0.01**	**Confidence level** *Razina značajnosti*
Wood species (A) *vrsta drva (A)*	2356535.75	2	1178267.875	2266.147	0.000	0.990
Processing time (B) *trajanje obrade (A)*	40028.88	1	40028.88	76.987	0.000	0.616
Process type (C) *vrsta obrade (C)*	7951.75	1	7951.75	15.293	0.000	0.242
A × B	159570.72	2	79785.356	153.450	0.000	0.865
A × C	68615.265	2	34307.632	65.983	0.000	0.733
B × C	63866.466	1	63866.466	122.834	0.000	0.719
A × B × C	262777.716	2	131388.858	252.698	0.000	0.913
Error	24957.275	48	519.943			
Sum	21608189.146	60				

cell wall layers. Micro-cracks in the S1 layer cause a decrease in resistance. Tomak and Yıldız (2012) also reported some decreases in the compressive strength, parallel to the fibers of vegetable oil-impregnated wood. Increasing of waiting time from 20 min to 40 min generally decreased the strength by 22 to 29 %. 20 min impregnation time with Imersol-Aqua caused a 17 % reduction in strength whereas 40 min time caused a 32 % reduction based on the impregnating agent as compared to control samples. 20 min and 40 min impregnation times with paraffin linseed oil caused 28 % and 26 % strength reductions, respectively. So, it was determined that strengths were reduced with regard to increased waiting time. On the basis of tree species, 6 % and 31 % reduction in tensile strength was observed with Scots pine and black locust, respectively, and a 7 % increase in tensile strength with sessile oak.

Table 5 clearly shows that the ranking can be done from the worst to the best as follow: Scots pine, black locust, and sessile oak in terms of tensile strength. So, sessile oak can be suggested for woodworking since the best tensile strength was obtained. The results of binary comparison made based on tree species, process type and processing time interaction level, which were found to be significant, are given in Table 6. 20 min waiting time can be suggested for woodworking materials since the 19 % improvement was achieved in tensile strength in comparison to 40 min waiting time.

Regarding the amount of reduction in performance against control samples in terms of process type, it was 24 % for Imersol-Aqua impregnated samples, and 27 % for samples impregnated with paraffin linseed oil.

The decrease of diagonal tension performance of treated wood might be because of bio-oil complex chemistry and reactions with wood. Bio-oils are composed of a mixture of water, guaiacols, catecols, syringols, vanillins, furan-carboxaldehydes, isoeugenol, pyrones, acetic, formicandcarbox-ylicacid, hydroxyalhydes, hydroxyketones, sugars and phenolics (Mohan *et al*., 2008; Dubey, 2010; Temiz *et al*., 2013). Due to their amphoteric properties, some bio-oil components may penetrate into the cell wall and change the mechanical properties. The strength losses of wood caused

Table 5 Results of comparison of the average diagonal tension performance by factors (N·m)
Tablica 5. Rezultati usporedbe srednjih vrijednosti dijagonalnog naprezanja prema faktorima (N·m)

Factors / *Činitelji*		**Tensile strength, N·m** *Vlačna čvrstoća,* N·m	**Difference, %** *Razlika, %*	**HG**
Wood species *Vrsta drva*	Black locust / *bagremovina*	519.981	-39.71	B
	Scots pine / *borovina*	335.164	-43.44	C
	Sessile oak / *drvo hrasta kitnjaka*	816.340	2.28	A*
	LSD: 153.88 A*: The highest value / *najveća vrijednost*			
Processing time *Trajanje obrade*	20 min	582.992	-22.38	A*
	40 min	531.331	-29.25	B
	Control	751.042	-	-
	LSD: 197.57 A*: The highest value / *najveća vrijednost*			
Process type *Vrsta obrade*	Imersol-Aqua	568.674	-24.28	A*
	Linseed oil / *laneno ulje*	545.649	-27.35	B
	Control / *kontrolni uzorak*	751.042	-	-
	LSD: 162.20 A*: The highest value / *najveća vrijednost*			

Table 6 Results of binary comparison of diagonal tension performance made based on process type, processing time and tree species interaction level (N·m)
Tablica 6. Rezultati binarne usporedbe dijagonalnog naprezanja na razini interakcije vrste obrade, trajanja obrade i vrste drva (N·m)

Processing time *Trajanje obrade*	**Tree species** *Vrsta drva*	**Black locust** *Bagremovina*			**Scots pine** *Borovina*			**Sessile oak** *Drvo hrasta kitnjaka*		
	Process type *Vrsta obrade*	Tensile strength *Vlačna čvrstoća*	Diff. %	HG	Tensile strength *Vlačna čvrstoća*	Diff. %	HG	Tensile strength *Vlačna čvrstoća*	Diff. %	HG
20 min	Imersol-Aqua	696.059	-19.29	E	446.274	-24.69	G	739.065	-7.40	D
	Paraffin linseed oil *parafinsko laneno ulje*	534.713	-38.00	F	244.049	-58.81	I	837.795	4.97	B
40 min	Imersol-Aqua	461.807	-46.46	G	189.111	-68.09	İ	879.734	10.23	A
	Paraffin linseed oil *parafinsko laneno ulje*	387.347	-55.09	H	461.224	-22.16	G	808.768	1.33	C
Control / *kontrolni uzorak*		862.466	-	-	592.548	-	-	798.114	-	-

LSD: 37.88 A*: The highest value / *najveća vrijednost*

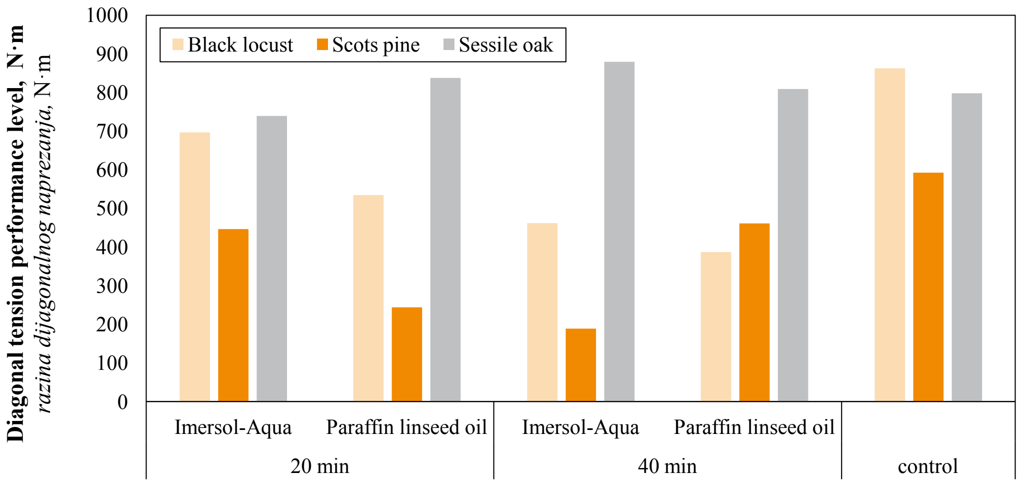

Figure 3 Interaction of tree species, process type and processing time
Slika 3. Interakcija vrste drva te vrste i trajanja obrade

by wood preservatives are directly related to its chemistry and severity of its fixation/precipitation reaction with wood (Temiz *et al*., 2013).

The highest average diagonal tension performance in terms of process type, processing time and tree type interaction was obtained for sessile oak test samples that were processed with Imersol-Aqua for 40 min (879.734 Nm), while the lowest was obtained on Scots pine test samples that were impregnated with Imersol-Aqua for 40 min (189.911 Nm), as shown in Figure 3.

4 CONCLUSIONS
4. ZAKLJUČAK

This study has been conducted in order to determine the effect of the short-term dip impregnation method with paraffin linseed oil and Imersol-Aqua on diagonal tension performance. The following conclusions can be drawn from this study.

The amount of retention in the long-term dipping (40 min.) of Scots pine, sessile oak and black locust was found to be higher than that of short-term dipping (20 min). On the other hand, the amount of retention was observed as sufficient in pine and higher than expected in black locust. The lowest amount of retention was found in pine and oak woods. This may be due to pit aspiration in pine and tyloses in oak. In a similar research, it was reported that, in the impregnation of Scots pine and oriental beech, the retention increased with the increase of impregnation time (Ör *et al*., 2006; Keskin *et al*., 2008).

In this study, the minimum strength decrease of around 68 % was obtained by Scots pine impregnated with Imersol-Aqua for 40 min and the highest strength increase of around 10 % was obtained for sessile oak samples impregnated with Imersol-Aqua for 40 min.

Finally, the highest diagonal tension performance of 879.734 Nm was obtained for oak samples impregnated with Imersol Aqua for 40 min., and the lowest diagonal tension performance of 189.11Nm was obtained for Scots pine samples impregnated with Imersol-Aqua for 40 min.

As a result, if the 5 % performance difference obtained after 20 minutes of paraffin linseed oil impregnation and 40 minutes of Imersol-Aqua impregnation is negligible, paraffin linseed oil treated stemless sessile oak can be recommended, especially since the production time is an important factor in mass production and due to the fact that it is made of organic material.

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