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Shear Force Capacities of H-Type Furniture Joints Constructed of Various Heat-Treated Wood Species

Kapaciteti posmične sile spojeva namještaja H-tipa izrađenoga od različitih toplinski tretiranih vrsta drva

ORIGINAL SCIENTIFIC PAPER
Izvorni znanstveni rad
Received – prispjelo: 26. 1. 2022.
Accepted – prihvaćeno: 18. 3. 2022.
UDK: 684.4.058
https://doi.org/10.5552/drvind.2023.0010

ABSTRACT • *The aim of this study was to investigate the effect of wood species, heat treatment, adhesive type and joint technique on shear force capacity of H-type furniture joints. For this purpose, an experimental design that consisted of 3 wood species, 2 treatment processes (untreated, heat-treated), 2 adhesive types (polyurethane (PUR), polyvinyl acetate (PVAc)) and 2 joint techniques (dowel, mortise-tenon (MT)) and 5 replications for each group were prepared, and accordingly, a total of 120 specimens were tested under static shear loads. Siberian pine (Pinus sibirica), Iroko (Chlorophora excelsa), and common ash (Fraxinus excelsior), which are commonly used in furniture constructions, were used as wood species. In general, iroko showed the highest shear force capacity between the wood species. The specimens constructed of heat-treated wood species showed lower shear force capacity by approximately 15 % in comparison to the same untreated specimens. MT joints showed better performance than dowel joints higher by approximately 21 %. PVAc adhesive gave higher values than PU adhesive by around 5 %. According to the results of four-way interactions, highest shear force capacities of H-type joints were obtained from "Common ash-PVAc-MT" combination in groups of untreated specimens and from "Iroko-PU-MT" combination in groups of heat-treated specimens.*

KEYWORDS*: heat-treated wood; H-type joint; mortise and tenon joint; dowel joint; shear force capacity*

SAŽETAK • *Cilj ovog istraživanja bio je ispitati utjecaj vrste drva, njegove toplinske obrade, vrste ljepila i tehnike spajanja na kapacitet posmične sile spojeva namještaja H-tipa. Za tu je namjenu pripremljen eksperiment s ovim parametrima: tri vrste drva, dvije obrade (netretirani i toplinski tretiran namještaj), dvije vrste ljepila (poliuretan – PUR, polivinilacetat – PVAc) i dvije tehnike spajanja (moždanikom te čepom i rupom – MT). Za svaki sustav pripremljeno je pet uzoraka te je pri statičkom posmičnom opterećenju ispitano ukupno 120 uzoraka. Odabrane su vrste drva koje se često upotrebljavaju u konstrukcijama namještaja: sibirski bor (Pinus sibirica), iroko (Chlorophora excelsa) i jasen (Fraxinus excelsior). Prema rezultatima istraživanja, drvo iroka pokazalo je najveći kapacitet posmične sile od svih ostalih vrsta drva obuhvaćenih eksperimentom. Uzorci izrađeni od toplinski obrađenog drva imali su oko 15 % manje vrijednosti kapaciteta posmične sile od netretiranih uzoraka. MT spojevi pokazali su za oko 21 % veće vrijednosti od spojeva s moždanicima. Uz upotrebu PVAc ljepila vrijednosti su bile*

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za oko 5 % veće od vrijednosti s PUR ljepilom. Prema rezultatima četverosmjernih interakcija, najveći kapaciteti posmične sile spojeva H-tipa dobiveni su za kombinaciju jasenovina – PVAc – MT u netretiranim uzorcima i za kombinaciju drvo iroka – PUR – MT u toplinski tretiranim uzorcima.

KLJUČNE RIJEČI: *toplinski obrađeno drvo; spoj H-tipa; spoj čepom i rupom; spoj moždanikom; kapacitet posmične sile*

1 INTRODUCTION
1. UVOD

Wood is a natural, sustainable and renewable structural material that has been used by humankind throughout the centuries. However, due to its organic composition, wood can be subjected to several types of degradation factors under adverse climate conditions that could negatively affect physical and mechanical properties of wood. Heat treatment is becoming popular in recent years to decrease the negative effects of those factors.

Heat treatment of wood is a kind of modification method that improves the properties of wood resulting in a new material that is more durable against environmental hazards as compared to the unmodified wood (Hill, 2011). During the heat treatment process, wood is subjected to high temperatures ranging from 160 to 280 °C for several hours in an environment with low oxygen content (Chanrion and Scheiber, 2002; Candelier *et al*., 2016). As a result of heat treatment process, dimensional stability and biological durability of wood are increased (Korkut *et al*., 2012; Kasemsiri *et al*., 2012; Romagnoli, 2015) but some physical and mechanical properties may decrease depending on conditions and intensity of the heat treatment (Viitaniemi 2000; Syrjanen 2001; Candelier *et al*., 2013; Romagnoli *et al*., 2015).

Heat-treated wood is an eco-friendly alternative to chemically treated wood and has a wide range of utilization within indoor and especially outdoor furniture applications. Garden furniture, such as tables, chairs, benches, etc., are some of those exposed to and affected by exterior weather conditions. Generally, frame construction technique, which usually consists of three types of joint combinations, namely, L-type (front leg to side rail), T-type (back leg to side rail), and H-type (back/front leg to side rail) joints is used to build this kind of furniture. Mortise and tenon (MT) joints and dowel joints are the most popular joint techniques to connect wooden frame members. The joints should be designed to resist the loads to which they will be exposed during the service life, since the joint strength is the most critical part of the whole frame construction. Typical loading conditions of joints of a simple sitting furniture are shown in Figure 1.

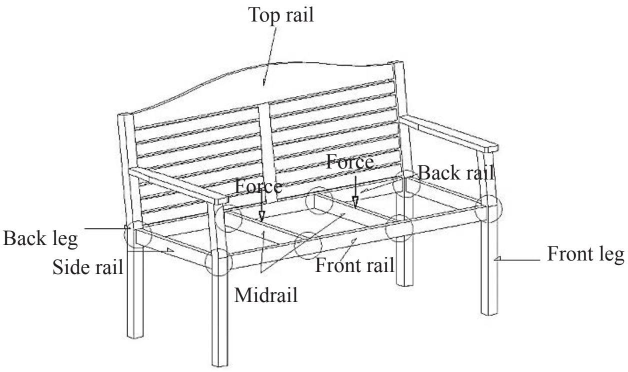


Figure 1 Typical loading conditions on a sitting furniture frame construction
Slika 1. Tipično opterećenje okvirne konstrukcije namještaja za sjedenje

When a sitting furniture frame is exposed to seat loading, the joints shown in circles in Figure 1, which are connected to side, front, back and mid-rails with back, front legs and rails, are subjected to coercive shear forces. The shear force capacities of the mentioned joints are quite important for the strength of the complete furniture frame.

Many factors, including wood species, adhesive type, tenon size, tenon shape, thickness of glue line, shape of fit, and moisture content (MC), etc., may affect the strength of the joints (Smardzewski, 2002; Dzincic and Skakic, 2012; Dzincic and Zivanic, 2014). Kasal *et al*. (2013) suggested that joints became stronger and stiffer as either tenon width or length increased. Prekrat and Smardzewski (2010) reported in their study that the shape of the glue line has a definite influence on the strength of the tenon joint. Najafi (2013) studied the withdrawal and shear strengths of dowel joints. Results showed that the withdrawal strength reduced up to 15 % due to moisture content conditions; furthermore, embedment diameter strongly affected withdrawal strength. Kasal *et al*. (2013) studied ultimate shear force capacity of various dowelled frame type furniture joints. According to the results, they reported that narrower dowel spacing provided greater shear force capacity. They also developed predictive expressions to estimate average shear force capacity of dowel joints. Stress and strain analysis of double-dowel case-type furniture corner joint was made by Hajdarevic and Martinovic (2016). Results of the study indicated that dowel spacing and distance from the edge of board have considerable effect on the stress state of the face and edge member; joints became stiffer when the distance between the dowels and board edge was rationally defined. Diler *et al*. (2017) studied the effect of wood species, heat treatment, adhesive type and of the study indicated that heat-treated specimens showed lower performance (by 25 %) than untreated specimens and all the factors mentioned above had significant effect on the withdrawal force capacity of T-type joints.

Previous studies show that numerical analysis theory is an alternative method to calculate the strength requirements for MT joints. In this context, an estimation formula was recommended by Erdil *et al*. (2005), which considers the effect of wood species, adhesive type, and joint geometry on the strength of MT joints. Kasal *et al*. (2016) compared the results of empirical tests and numerical analyses for various sizes of mortise and tenon joints. The results of the comparison showed that the numerical analyses gave reasonable estimates of mechanical behaviour of joint strength. Eckelman *et al*. (2017) improved a statistical technique that uses the same data to determine reduction factors and impact of the selection of any given confidence-proportion levels on design values for MT joints.

In addition, recent studies have shown that, with the development of computer technology, finite element method (FEM) has become widespread for the analysis of furniture systems and connections as well as complex structures. By the contribution of many researchers, finite element method (FEM) has been confirmed as an effective method commonly used in wood engineering (Kasal *et al*., 2016a; Kilic *et al*., 2018; Hu *et al*., 2019; Xi *et al*., 2020; Ceylan *et al*. 2021). Previous studies also proved that the FEM can be used to analyse some furniture joint techniques such as MT joint (Colakoglu *et al*., 2012; Smardzewski, 2016; Zhou, 2018; Kilic *et al*., 2018; Chen, 2019; Zhang, 2021). By use of an advanced finite element software, it is possible to perform accurate simulations of the behaviour of furniture constructions under loading conditions.

It is believed that the use of the heat-treated wood in furniture products will increase by expanding the knowledge regarding its strength properties. Although the physical and mechanical properties of heat-treated wood materials have been investigated in many studies, the information on strength performance of furniture joints made of heat-treated wood is very limited. Thus, it is the aim of this study to investigate the effect of wood species, heat treatment, joint types, and adhesive types on shear force capacities of H-type furniture joints.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Materials
2.1. Materijali

In this study, three wood species, namely, Siberian pine (*Pinus sibirica*), iroko (*Chlorophora excelsa*) and common ash (*Fraxinus excelsior*) were used as wood materials. Since all these wood materials were commonly used in the wood products industry, they are potential wood species for industrial scale heat treatment. All heat-treated and untreated wood materials were provided by Novawood Company in Gerede, Turkey.

According to information gathered from , company, heat treatment process was applied according to that described in Finnish ThermoWood Handbook (Finnish Thermowood Association, 2003). The total heat treatment time was 63h, while the time of exposure to the highest temperature was 3h. The heat treatment operation was performed slowly because of the risk of cracks and drying defects. The specimens were prepared from selected defect free materials after heat treatment. Untreated planks of the same species, as control specimens, were dried in industrial drying kilns at approximately 70 °C and 65 % relative humidity (RH), until they reached an equilibrium moisture content. Care was given to select defect-free wood materials for preparing all test specimens. All the prepared specimens were conditioned at (20±2) °C and (65±3) % RH until an equilibrium was achieved before testing.

Moisture content (MC) of control specimens and heat-treated specimens was measured during testing in a range of 6-8 % and 3-5 %, respectively. MC and density (δ) of wood materials were measured according to procedures described in ASTM D 4442-92 (2001) and ASTM D 2395-14 (2015), respectively. In addition, tensile strength and compression strength in parallel to the grain and ultimate bending strength of wood materials were determined according to the test procedures described in ASTM D 143-94 (2000).

Results of some physical and mechanical properties of wood species used in this study are given in Table 1 and Table 2, respectively. According to the results, density of heat-treated wood materials was lower than that of the same untreated species by 7.9 %, 5.2 %, and 6.8% for Siberian pine, iroko, and common ash, respectively. In general, Siberian pine had the lowest density, while common ash had the highest. In addition, the equilibrium MC values of heat-treated wood specimens were lower than those of the untreated specimens.

According to Table 2, all heat-treated wood species yielded lower values of tensile strength as compared to the same untreated specimens. Siberian pine decreased by approximately 16.7 %, iroko by 11 % and common ash by 3 %. On the other hand, results of compression strength were contrary to expectations and common literature (Unsal and Ayrilmis, 2005; Korkut *et al*., 2008); heat-treated specimens yielded higher values than untreated specimens by about 8 %, 19 %, 10 %, for Siberian pine, iroko, and common ash respectively. This could be explained by differences in moisture content between heat-treated and untreated wood specimens. In bending strength, heat-treated Siberian pine decreased by approximately 20 %, while

Table 1 Physical properties of wood materials (Demirci *et al*., 2016)
Tablica 1. Fizička svojstva drvnog materijala (Demirci *et al*., 2016.)

Wood species *Vrsta drva*	**Heat treatment** *Toplinska obrada*	**Test moisture content (*MC*), %** *Sadržaj vode (MC), %*	**Oven dry density (δ_o), g/cm³** *Gustoća u apsolutno suhom stanju (δ_o), g/cm³*	***COV**, %**	**Test *MC* density (δ_{MC}), g/cm³** *Gustoća pri ispitivanom sadržaju vode (δ_{MC}), g/cm³*	***COV**, %**
Siberian pine *sibirska borovina*	Heat-treated / *toplinski tretirana*	4.50	0.35	2.12	0.36	2.78
	Untreated / *netretirana*	6.77	0.38	4.02	0.40	4.54
Iroko *drvo iroka*	Heat-treated / *toplinski tretirano*	3.71	0.54	2.48	0.56	2.28
	Untreated / *netretirano*	7.54	0.57	3.01	0.61	2.59
Common ash *jasenovina*	Heat-treated / *toplinski tretirana*	4.24	0.55	2.26	0.57	2.24
	Untreated / *netretirana*	7.04	0.59	3.65	0.63	3.86

*COV: Coefficients of variation / *koeficijent varijacije*

Table 2 Mechanical properties of wood materials (Demirci *et al*., 2016)
Tablica 2. Mehanička svojstva drvnog materijala (Demirci *et al*., 2016.)

Wood species *Vrsta drva*	**Heat treatment** *Toplinska obrada*	**Tensile strength parallel to grain, N/mm²** *Čvrstoća na vlak u smjeru drvnih vlakanaca, N/mm²*	***COV*, %**	**Compression strength parallel to grain, N/mm²** *Čvrstoća na tlak u smjeru drvnih vlakanaca, N/mm²*	***COV*, %**	**Bending strength, N/mm²** *Čvrstoća na savijanje, N/mm²*	***COV*, %**
Siberian pine *sibirska borovina*	Heat-treated / *toplinski tretirana*	36.49	10.05	51.72	9.33	68.01	8.92
	Untreated / *netretirana*	43.81	9.27	47.64	3.92	85.31	9.33
Iroko *drvo iroka*	Heat-treated / *toplinski tretirano*	51.54	10.07	69.72	8.38	88.29	8.58
	Untreated / *netretirano*	57.78	5.66	56.70	6.27	87.51	8.21
Common ash *jasenovina*	Heat-treated / *toplinski tretirana*	69.25	9.30	77.73	2.69	137.67	6.18
	Untreated/ *netretirana*	71.21	9.26	69.71	3.68	138.44	7.49

there was no significant difference between heat-treated and untreated specimens of iroko and common ash.

Polyvinyl acetate (PVAc) and polyurethane (PUR) adhesives were used to assemble the test specimens in this study. According to specifications in data sheet of the suppliers, viscosity of PVAc was 160 cps to 200 cps at 25 °C with a density of 1.09 g/cm³, 50 % solids content, liquid form and water resistance, viscosity of PUR was 3300 cps to 4000 cps at 25 °C with a density of 1.11 g/cm³ and one component. The adhesives were applied at (150 ± 10) g/m² in accordance with suppliers' recommendation.

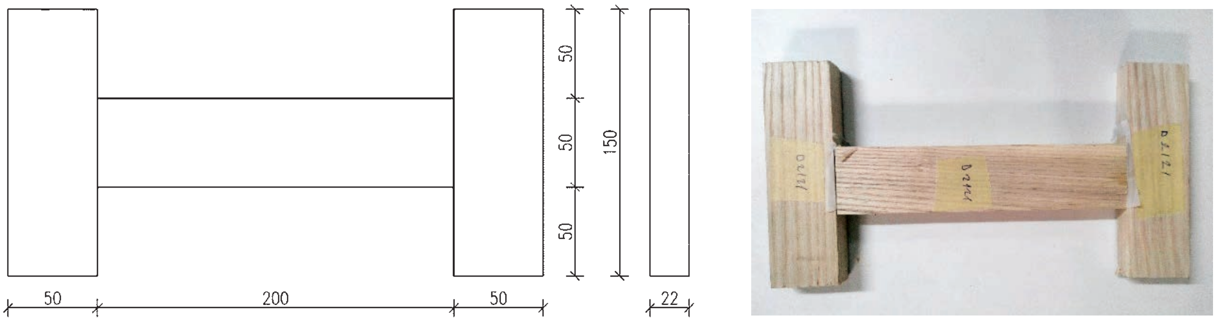
2.2 General configuration and construction of test specimens

2.2. Opća konfiguracija i konstrukcija ispitnih uzoraka

In this study, a total of 120 H-type joint specimens, constructed of 3 different wood species (WS), 2 heat treatments (HT), 2 adhesive types (AT), and 2 joint techniques (JT) with 5 replications for each group, were prepared and tested. Each test specimen was constructed with three structural elements, a post (200 mm × 50 mm × 22 mm) and two rail (150 mm × 50 mm × 22 mm) members. Technical drawing of the specimen and an assembled specimen are shown in Figure 2a and 2b, respectively.

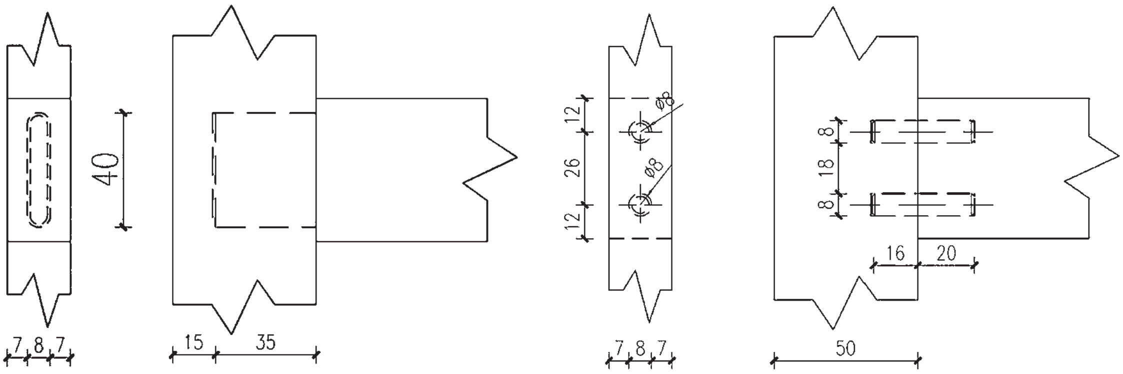
In the MT joint specimens, mortise and tenon connections were produced with a mortising and tenoning machine. The dimensions of tenons measured were 35 mm × 40 mm × 8 mm (length×width×thickness), and a snug fit (average mortise-tenon clearance of (0.076±0.025 mm) was obtained between tenons and mortises. Adhesive of (150±10) g/m² was applied approximately to all tenon and mortise faces.

Dowel joints were constructed according to TS 4539 (1985). In the dowel joint specimens, multi-groove beech (*Fagus orientalis* L.) dowels with 8 mm in diameter and 36 mm in length were used. Two dowels were used in each joint with a 26 mm centreline distance. Dowels were embedded at the depth of 20 mm in the rail and 16 mm in the post members. Clearances of dowel-hole were not measured, but all dowels fit snugly into the holes. Adhesive was spread over the sides of the holes and all faces of the dowels. Wax paper was used to prevent adhering between the specimen members. All specimens were assembled manually one by one with a clamp under the pressure specified in the adhesive data sheet. Prior the test, all the test specimens were allowed to cure for minimum one month in an environmentally controlled conditioning room that was set to (65±3) % relative humidity and (20±2) °C. Technical details of the MT and dowel joints are given in Figure 3a and 3b, respectively.



(a) (b)

Figure 2 Test specimen dimensions (a) and real picture (b) (dimensions in mm)
Slika 2. Dimenzije ispitnog uzorka (a) i stvarna slika uzorka (b) (dimenzije u mm)



(a) (b)

Figure 3 MT (a) and dowel (b) joints details (dimensions in mm)
Slika 3. Detalji spoja čepom i rupom (a) i spoja moždanikom (b) (dimenzije u mm)

2.3 Testing method
2.3. Metoda ispitivanja

All the static tests and shear force capacity tests were conducted on a 50-kN capacity screw type universal-testing machine (Mares 2007, Turkey) under 6 mm/min static loading rate in the Physical and Mechanical Tests Laboratory of Wood Science and Industrial Engineering Department of Mugla Sitki Kocman University. Tensile and compression strength parallel to the grain and bending strength of the wood materials were determined according to the test procedures described in ASTM D 143-94 (2000). Shear force capacity tests were conducted based on the methods accepted in previous studies (Ors and Efe 1998; Dizel 2005; Yildirim et al. 2020, Balikci 2015). For the static tests, samples were loaded to ultimate failure; however, for the shear force capacity test samples, loading was continued until separation occurred on the intersecting surfaces. The test set-up used for shear force capacity tests is illustrated in Fig. 4. The ultimate force monitored on H-type joint specimens was recorded as the shear force in Newton (N). The maximum force for H-type joint elements was recorded as shear force capacity and calculated by following equation:

$$F = \frac{F_{\max}}{2} \qquad (1)$$

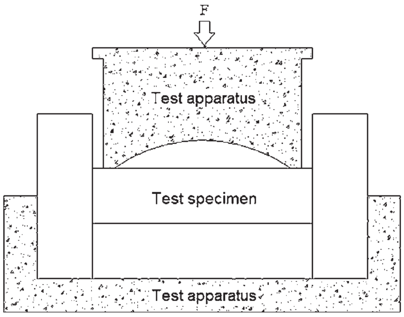


Figure 4 Shear force capacity test set-up
Slika 4. Postav za ispitivanje kapaciteta posmične sile

F – Shear force capacity of a joint (N)
$F_{\max}$ – Maximum force (N),
2 – Number of joints.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Experimental results for shear force capacity of H-type joints
3.1. Eksperimentalni rezultati kapaciteta posmične sile spojeva H-tipa

In shear force capacity tests, specimens reached ultimate values within 60-90 seconds. Commonly, all untreated specimen combinations failed due to glue

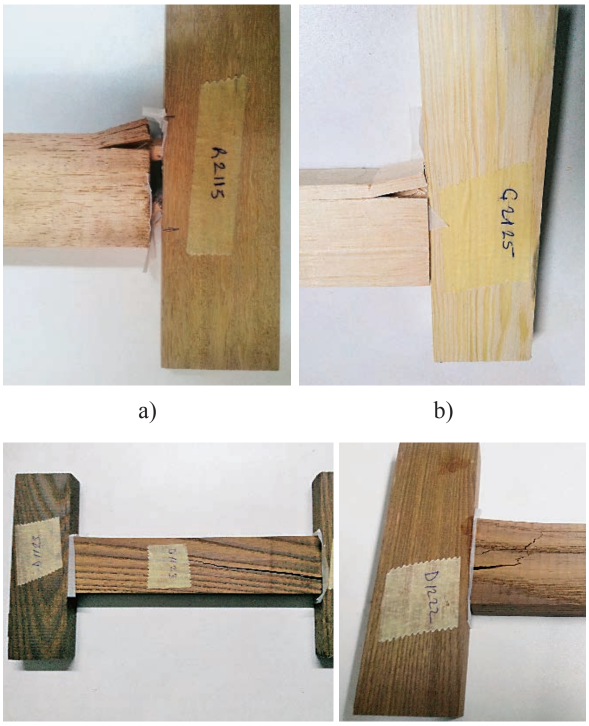


Figure 5 Typical failure modes of untreated (a) and heat-treated (b) specimens (Force directions are all from the top of photographs)
Slika 5. Tipični načini loma netretiranih (a) i toplinski tretiranih (b) uzoraka (sile su usmjerene od vrha fotografija prema dolje)

line fractures and cracking from upper edge of rail members as shown in Figure 5a. However, in the case of heat-treated specimens, generally, joints fractured from glue line and split from the middle or toward upper edge of rail members as shown in Figure 5b.

A four-way analysis of variance (MANOVA) general linear model procedure was performed to analyse the main effects and interactions on the shear force capacity. Statistically significant results were further analysed by the least significant difference (LSD) multiple comparisons procedure at 5 % significance level to determine the mean differences of shear force capacity values of H-type joints tested considering the wood species, heat treatment, adhesive type, joint technique, and their interactions. MSTAT-C statistical software (Michigan State University, USA) was used for statistical evaluations. Multiple variance analysis results on the effect of wood species (WS), treatment process (HT), adhesive types (AT) and joint types (JT) on the shear force capacity of H-type joints are given in Table 3.

According to the results given in Table 3, all single and multiple interactions, except for "WS - HT - AT" and "WS - AT - JT", were statistically significant at 5 % significance level. For the main factors and four-way interactions, least significant difference (LSD) multiple comparisons at 5 % significance level were performed to determine mean differences in shear capacity of H-type joints.

Mean comparison results of the effect of wood species on the shear force capacity of the joints are shown in Table 4. The single LSD value was calculated as 270.7 N based on the error mean square of the full model.

According to Table 4, the effect of wood species on the shear force capacity of the H-type joints was statistically significant at 5 % significant level. Iroko yielded the highest shear force capacity. Accordingly, the results of common ash and Siberian pine were lower than

Table 3 Results of multiple variance analysis
Tablica 3. Rezultati analize višestruke varijance

Variation sources *Izvori varijacija*	**Degrees of freedom** *Stupnjevi slobode*	**Sum of squares** *Zbroj kvadrata*	**Mean square** *Srednji kvadrat*	***F*-value** *F-vrijednost*	**Probability (p<0.05)** *Vjerojatnost (p<0,05)*
WS	2	63743904.9	31871952.4	1739	0.0000
HT	1	10887157.118	10887157.118	59.4184	0.0000
WS - HT	2	7237462.381	3618731.191	19.7498	0.0000
AT	1	1188764.315	1188764.315	6.4879	0.0125
WS - AT	2	2880596.895	1440298.448	7.8607	0.0007
HT - AT	1	4442058.017	4442058.017	24.2433	0.0000
WS - HT - AT	2	695591.768	347795.884	1.8982	NS
JT	1	21249549.778	21249549.778	115.9729	0.0000
WS - JT	2	4273179.314	2136589.657	11.6608	0.0000
HT - JT	1	4764828.825	4764828.825	26.0048	0.0000
WS - HT - JT	2	7672005.539	3836002.770	20.9356	0.0000
AT - JT	1	7789169.147	7789169.147	42.5107	0.0000
WS - AT - JT	2	15635.711	7817.855	0.0427	NS
HT - AT - JT	1	3477986.129	3477986.129	18.9817	0.0000
WS - HT - AT - JT	2	1279682.618	639841.309	3.4920	0.0344
Error	96	17589946.561	183228.610		
Total	119	159187518.977			

NS – Not significant / *nije značajno*, WS – Wood species / *vrsta drva*, HT – Heat treatment / *toplinska obrada*, AT – Adhesive type / *vrsta ljepila*, JT – Joint technique / *vrsta spoja*

Table 4 Mean comparisons of effect of wood species on shear force capacity
Tablica 4. Usporedbe srednjih vrijednosti utjecaja vrste drva na kapacitet posmične sile

Wood species *Vrsta drva*	**Shear force capacity**, N *Kapacitet posmične sile,* N	
	X	HG
Siberian pine / *sibirski bor*	2653	C
Iroko / *drvo iroka*	4304	A
Common ash / *jasenovina*	4067	B

LSD± 270.7 N, HG – Homogeneity group / *homogene grupe*

Table 5 Mean comparisons for heat treatment effect on shear force capacity
Tablica 5. Usporedbe srednjih vrijednosti utjecaja toplinskog tretmana na kapacitet posmične sile

Heat treatment *Toplinska obrada*	**Shear force capacity**, N *Kapacitet posmične sile,* N	
	X	HG
Heat-treated / *toplinski tretirano*	3374	B
Untreated / *netretirano*	3976	A

LSD± 155.1 N

Table 6 Mean comparisons for effect of adhesive type on shear force capacity
Tablica 6. Usporedbe srednjih vrijednosti utjecaja vrste ljepila na kapacitet posmične sile

Adhesive type *Vrsta ljepila*	**Shear force capacity**, N *Kapacitet posmične sile,* N	
	X	HG
PUR	3575	B
PVAc	3774	A

LSD± 155.1 N

Table 7 Mean comparisons for effect of joint technique on shear force capacity
Tablica 7. Usporedbe srednjih vrijednosti utjecaja tehnike spajanja na kapacitet posmične sile

Joint technique *Tehnika spajanja*	**Shear force capacity**, N *Kapacitet posmične sile,* N	
	X	HG
Dowel / *moždanik*	3254	B
MT	4096	A

LSD± 155.1 N

those of iroko by approximately 5.5 % and 38 %, respectively, whereas the results of common ash were higher than those of Siberian pine by approximately 35 %.

The mean comparison values of the effect of heat treatment on shear force capacity of tested H-type joints are presented in Table 5. The single LSD value was calculated as 155.1 N based on the error mean square of the full model.

The specimens constructed of heat-treated wood species performed lower than the untreated specimens in terms of shear force capacity. The performance of the joints decreased by approximately 15 % as compared to the untreated specimens. This could be due to the fact that heat treatment processing causes the physical changes in the cellular structure of wood. The negative effects of the heat treatment process on the mechanical properties of wood materials have been well researched in the previous studies (Esteves and Pereira, 2009). As a result of thermal process, strength loss associated with thermal degradation and mass loss due to applied temperature may occur (Rusche, 1973; Zaman *et al*., 2000; Mazela *et al*., 2003). Mitchel (1998) indicated that irreversible degradation of the mechanical and technological properties of wood are caused by thermal degradation.

The mean comparison values of the effect of adhesives on shear force capacity of tested H-type joints are given in Table 6. The single LSD value was calculated as 155.1 N based on the error mean square of the full model.

In this study, PVAc adhesive performed better than PU adhesive by approximately 5.3 % higher values in terms of the shear force capacity of H-type joints. PU and PVAc are structurally different adhesives. PUR is a thermosetting adhesive that results in a rigid material after curing, while PVAc is a thermoplastic adhesive with more elastic behaviour after curing. It is deduced that these properties of adhesives may affect the results and that PVAc might perform better in terms of mechanical adhesion of these kind of joints.

The mean comparison values for the effect of joint technique on the shear force capacity of tested H-type joints are presented in Table 7. The single LSD value was calculated as 155.1 N based on the error mean square of the full model.

According to Table 7, MT joints performed better than dowel joints by approximately 21 % in terms of shear force capacity. The results suggest that MT joints perform better where shear force capacity is needed. This may be explained by the fact that the bonding surface area of MT joints is larger than that of dowel joints.

The mean comparison values of the effect of four-way interactions on shear force capacity of tested H-type joints are given in Table 8. LSD was calculated as 537.4 N.

According to Table 8, in general, all combinations made of untreated wood species yielded higher values than combinations made of heat treated species except for “Iroko-PUR-MT combination. “Common ash–Untreated–PVAc–MT” combination showed the highest shear force capacity in this study. Among combinations made of heat-treated wood species, the highest performance was obtained with “Iroko-PUR-MT” and “iroko-PVAc-MT” combinations, and there was no significant difference between the two combinations,

Table 8 Mean comparison results of effect of four-way interactions with coefficient variations on shear force capacity
Tablica 8. Usporedba rezultata srednjih vrijednosti četverosmjernih interakcija s koeficijentima varijacije na kapacitet posmične sile

Wood species *Vrsta drva*	**Heat treatment** *Toplinska obrada*	**Adhesive type** *Vrsta ljepila*	**Joint type** *Vrsta spoja*	**Shear force capacity, N** *Kapacitet smične sile,* N		***COV*, %**
				X	HG	
Siberian pine *sibirski bor*	Heat-treated *toplinski tretiran*	PUR	Dowel	2826	H	11.06
			MT	2446	HI	7.88
		PVAc	Dowel	2051	I	6.55
			MT	2510	HI	11.65
	Untreated *netretiran*	PUR	Dowel	2832	H	9.28
			MT	2880	GH	8.65
		PVAc	Dowel	2273	I	13.30
			MT	3407	FG	16.21
Iroko *drvo iroka*	Heat-treated *toplinski tretirano*	PUR	Dowel	3763	DEF	13.14
			MT	4989	C	9.18
		PVAc	Dowel	3378	FG	10.63
			MT	4814	C	7.58
	Untreated *netretirano*	PUR	Dowel	3964	DE	13.06
			MT	4080	D	19.89
		PVAc	Dowel	3749	DEF	5.95
			MT	5695	B	13.32
Common ash *jasenovina*	Heat-treated *toplinski tretirana*	PUR	Dowel	3399	FG	20.53
			MT	3376	FG	8.21
		PVAc	Dowel	3495	EF	15.15
			MT	3436	EF	12.35
	Untreated *netretirana*	PUR	Dowel	3671	DEF	7.51
			MT	4677	C	9.26
		PVAc	Dowel	3646	DEF	6.83
			MT	6838	A	6.17

LSD± 537.4 N

while “Siberian pine-HT–PVAc–Dowel” combination showed the lowest values.

There was no significant difference between “Siberian pine-HT-MT” combinations constructed with both PUR and PVAc adhesives. A similar situation occurred when both MT and Dowel joints were constructed with a the combination of “iroko-HT-PUR” and “iroko-HT-PVAc”. In addition, when comparing their combinations, no significant difference was found when both MT and Dowel joints were constructed with combinations of “Common ash-HT-PUR” and “Common ash-HT-PVAc”.

It is believed that these results could provide economic and technical benefits for furniture designers, engineers, and manufacturers.

4 CONCLUSIONS
4. ZAKLJUČAK

In this study, shear force capacity of H-type joints made of heat-treated Siberian pine, Iroko and Common Ash were investigated. From results of the study, it can be concluded that wood species, heat treatment, adhesive type, and joint type had significant effects on the shear force capacity of H-type joints. In terms of adhesive type, PVAc could be considered as a better alternative, while the MT joint type could be preferred where high strength was necessary.

In terms of wood species, iroko showed higher shear force capacity values than common ash and Siberian pine. Shear force capacity of the specimens made of heat-treated wood was by approximately 15 % lower than that of the untreated specimens. As stated in many previous studies, the present study also confirmed that heat treatment has negative effects on the mechanical properties of wood. In terms of the adhesive type, the joints glued with PVAc had approximately 5 % higher shear force strength than those glued with PUR. In terms of the joint type, MT joints performed approximately 21 % better than dowel joints. For the specimens made of heat-treated wood materials, the best results were obtained from the iroko-PUR-MT and iroko- PVAc- MT combinations, and there was no significant difference between the two combinations.

It is believed that the results of this study will help design more durable furniture frame constructions, especially for sitting furniture, since most of their joints are exposed to shear effect under applied forces. The results of the study clearly indicate that designers/engineers should select the joint type, wood species, and adhesive, when using heat treated materials, in order to reduce the effects of strength reductions caused by heat treatment. In future studies, different wood species and joint types could be evaluated in order to make a wider range of engineering decisions. Such wide range of studies could also provide opportunity to create predictions for optimum strength of joints designed with heat treated materials.

Acknowledgements – Zahvala

This article is a part of MSc. thesis of second author (Balikci, 2015). It may contain some common data and similarities with the papers published by Diler et al. (2017) and Demirci et al. (2016) which are also a part of the same MSc. thesis. This study was supported by Scientific Research Project Office of Mugla Sitki Kocman University with project no 14/023. A part of this article was presented verbally in Proceedings of 28th International Conference Research for Furniture Industry in Poznan/Poland in 2017.

5 REFERENCES
5. LITERATURA

1. Balikci, E., 2015: Mechanical properties of the frame construction furniture joints prepared of heat-treated wood. Master Thesis, Mugla Sitki Kocman University, Institution of Natural Sciences, Mugla, Turkey.
2. Candelier, K.; Dumarcay, S.; Petrissans, A.; Desharnis, L.; Gerardin, P.; Petrissans, M., 2013: Comparison of chemical composition and decay durability of heat-treated wood cured under different inert atmospheres: nitrogen or vacuum. Polymer Degradation and Stability, 98 (2): 677-681. https://doi. org/10.1016/j.polymdegradstab.2012.10.022
3. Candelier, K.; Thevenon, M. F.; Petrissans, A.; Dumarcay, S.; Gerardin, P.; Petrissans, M., 2016: Control of wood thermal treatment and its effects on decay resistance: a review. Annals of Forest Science, 73 (3): 571-583. https://doi.org/10.1007/s13595-016- 0541-x
4. Ceylan, E.; Guray, E.; Kasal, A., 2021: Structural analyses of wooden chairs by finite element method (FEM) and assessment of the cyclic loading performance in comparison with allowable design loads. Maderas, Ciencia y tecnologia, 19 (23): 1-16.
5. Chanrion, P.; Schreiber, J., 2002: Bois traité par haute temperature. Paris: CTBA.
6. Chen, Y.; Yang, Y.; Zhang, Z., 2019. Study on small-diameter wood scrimber and furniture design. Journal of Forestry Engineering, 4 (1): 155-159.
7. Colakoglu, M. H.; Apay, A. C., 2012: Finite element analysis of wooden chair strength in free drop. International Journal of Physical Sciences, 7 (7): 1105-1114.
8. Demirci, S.; Acar, M.; Balikci, E.; Diler, H.; Erdil, Y. Z., 2016: Comparison of some physical and mechanical properties of various heat-terated and untreated wood. In: Proceedings of II. International Furniture Congress, Mugla, Turkey, pp: 121-127.
9. Diler, H.; Acar, M.; Balikci, E.; Demirci, S.; Erdil, Y. Z., 2017: Withdrawal force capacity of T-type furniture joints constructed from various heat-treated wood species. BioResources, 12 (4): 7466-7478.
10. Dizel, T., 2005: Mechanical behavior of properties of the frame type furniture joints constructed of laminated veneer lumber. Master Thesis, Gazi University, Institution of Natural Sciences, Ankara, Turkey.
11. Dizel, T.; Efe, H.; Kuşkun, T.; Kasal, A., 2016: Tensile strength of T-type joints constructed with laminated veneer lumber. In: Proceedings of II. International Furniture Congress, Muğla, Turkey, pp. 100-104.
12. Dzincic, I.; Skakic D., 2012: Influence of type of fit on strength and deformation of oval tenon-mortise joint. Wood Research, 57 (3): 469-477.
13. Dzincic, I.; Zivanic, D., 2014: The influence of fit on the distribution of glue in oval tenon/mortise joint. Wood Research, 59 (2): 297-302.
14. Eckelman, C. A.; Haviarova, E.; Kasal, A.; Erdil, Y. Z., 2017: Technical note: Lower tolerance limit approach to equation-based rational design values for t-shaped mortise and tenon joints. Society of Wood Science and Technology, 49 (1): 113-121.
15. Erdil, Y. Z.; Kasal, A.; Eckelman, C. A., 2005: Bending moment capacity of rectangular mortise and tenon furniture joints. Forest Products Journal, 55 (12): 209- 213.
16. Esteves, B. M.; Pereira, H., M., 2009: Wood modification by heat treatment: a review. BioResources, 4 (1): 370-404.
17. Hajdarevic, S.; Martinovic, S., 2016: The effect of dowel spacing on the stress and strain of case-type furniture corner joint. In: Proceedings of the 26th DAAAM International Symposium, Vienna, Austria, pp. 392-399.
18. Hill, C. A .S., 2011: Wood modification: chemical, thermal and other processes. Wiley, Chichester, UK.
19. Hu, W.; Guan, H., 2019: A finite element model of semirigid mortise-and-tenon joint considering glue line and friction coefficient. Journal of Wood Science, 65: 14. https://doi.org/10.1186/s10086-019-1794-4
20. Kasal, A.; Kuskun, T.; Haviarova, E.; Erdil, Y. Z., 2013: Static front to back loading capacity of wood chairs and relation between chair strength and individual joint strength. BioResources, 11 (4): 9359-9372. https://doi. org/10.15376/biores.11.4.9359-9372
21. Kasal, A.; Erdil, Y. Z.; Demirci, S.; Eckelman, C. A., 2013: Shear force capacity of various doweled frame type furniture joints. Kastamonu University, Journal of Forestry Faculty, 13 (1): 60-71.
22. Kasal, A.; Smarwzewski, J.; Kuskun, T.; Erdil, Y. Z., 2016: Numerical analyses of various sizes of mortise and tenon furniture joints. BioResources, 11 (3): 6836-6853. https://doi.org/10.15376/biores.11.3.6836-6853
23. Kasal, A.; Kuşkun, T.; Haviarova, E.; Erdil, Y. Z., 2016a: Static front to back loading capacity of wood chairs and relationship between chair strength and individual joint strength. BioResources, 11 (4): 9359-9372. https://doi. org/10.15376/biores.11.4.9359-9372
24. Kasemsiri, P.; Hiziroglu, S.; Rimdusit, S., 2012: Characterization of heat treated eastern redcedar (*Juniperus virginiana* L.). Journal of Materials Processing Technology, 212 (6): 1324-1330. https://doi.org/10.1016/j. jmatprotec.2011.12.019
25. Korkut, S.; Akgül, M.; Dündar, T., 2008: The effects of heat treatment on some technological properties of Scots pine (*Pinus sylvestris* L.) wood. Bioresource Technology, 99: 1861-1868.
26. Korkut, S.; Korkut, D. S.; Kocaefe, D.; Elustondo, D.; Bajraktari, A.; Cakicier, N., 2012: Effect of thermal modification on the properties of narrow-leaved ash and chestnut. Industrial Crops and Products, 35 (1): 287-294. https://doi.org/10.1016/j. indcrop.2011.07.016
27. Mazela, B.; Zakrzewski, R.; Grzeskowiak, W.; Cofta, G.; Bartkowiak, M., 2003: Preliminary research on the bio-

logical resistance of thermally modifies wood. In: Proceedings of the First European Conference on Wood Modification, Ghent, Belgium.
28. Mitchell, P. H., 1988: Irreversible property changes of small loblolly pine specimens heated in air nitrogen oroxygen. Wood and Fiber Science, 20 (3): 320-355.
29. Najafi, A., 2013: Investigation on the strengths of T-shape joint. Middle-East Journal of Scientific Research, 15: 398-402.
30. Ors, Y.; Efe, H., 1998: Mechanical behavior of joint connectors on furniture (frame construction) design. Turkish Journal of Agriculture and Forestry, 22: 21-27.
31. Prekrat, S.; Smardzewski, J., 2010: Effect of glue line shape on strength of mortise and tenon joint. Drvna industrija, 61: 223-228.
32. Romagnoli, M.; Cavalli, D.; Pernarella, R.; Zanuttini, R.; Togni, M., 2015: Physical and mechanical characteristics of poor-quality wood after heat treatment. iForest – Biogeosciences and Forestry, 8: 884-891. https://doi.org/10.3832/ ifor1229-007
33. Rusche, H., 1973: Thermal degradation of wood at temperatures up to 200 °C. Part I: Strength properties of dried wood after heat treatment. Holz als Roh-und Werkstoff, 31: 273-281.
34. Smardzewski, J., 2002: Strength of profile-adhesive joints. Wood Science and Technology, 36 (2): 173-183.
35. Smardzewski, J., 2016: Numerical analysis of furniture constructions. Wood Science and Technology, 32 (4): 273-286. https://doi.org/10.1007/BF00702895
36. Syrjanen, T.; Oy, K., 2001: Production and classification of heat-treated wood in Finland, Review on heat treatments of wood. In: Proceedings of the special seminar held in Antibes, France.
37. Unsal, O.; Ayrilmis, N., 2005: Variations in compression strength and surface roughness of heat-treated Turkish river red gum. Journal of Wood Science, 51: 405-409.
38. Viitaniemi, P., 2000: New properties for thermally-treated wood. Indust. Horizons.
39. Yildirim, M. N.; Karaman, A.; Uslu, E., 2020: Determination of shear force capacity of H-type box furniture joints connected with different demountable type of connection elements. Journal of Adhesion Science and Technology, 34 (8): 867-876. https://doi.org/10.1080/01694243.2019.1688489
40. Zaman, A.; Alen, R.; Kotilainen, R., 2000: Heat behavior of *Pinus sylvestris* and *Betula pendula* at 200 – 230 °C. Wood and Fiber Science, 32 (2): 138-143.
41. Zhang, T.; Hu, W., 2021: Numerical study on effects of tenon sizes on withdrawal load capacity of mortise and tenon joint. Wood Research, 66 (2): 321-330.
42. Zhou, C. M.; Yu, M. N.; Zhou, T., 2018: Experimental study on three-dimensional shape mapping of complex furniture. EURASIP Journal on Image and Video Processing, 9: 89.
43. Xi, X.; Yang, Y.; Zhang, Z. F., 2020: Pull-out force and finite element analysis of T-type components of Vitex negundo L. scrimber with different node forms. Journal of Forestry Engineering, 5 (1): 182-187.
44. ***ASTM D 143-94, 2000: Standard test methods for small clear specimens of timber. ASTM International, West Conshohocken, PA, USA.
45. ***ASTM D 2395-14, 2015: Standard test methods for density and specific gravity (relative density) of wood and wood-base materials. ASTM International, West Conshohocken, PA, USA.
46. ***ASTM D 4442-92, 2001: Standard test methods for direct moisture content measurement of wood and wood-base materials. ASTM International, West Conshohocken, PA, USA.
47. ***Finnish ThermoWood Association, 2003: ThermoWood Handbook. Helsinki, Finland.
48. ***TS 4539, 1985: Wood Joints – The rules of dowel joints. Ankara, Turkey.

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