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Withdrawal force capacity of mortise and loose tenon T-type furniture joints

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Abstract: The main goal of this study was to determine the effect of wood species and loose tenon length on the withdrawal force capacity of mortise and loose tenon (M&LT) T-type furniture joints. The specimens were manufactured from oak (*Quercus alba*), beech (*Fagus orientalis* L.), poplar (*Populus deltoides*), sycamore (*Platanus orientalis*), fir (*Abies alba*), and white walnut (*Juglans cinerea*), and the tenon species selected was oriental beech (*Fagus orientalis* L.). The length of the tenon was determined on the basis of the length glued into the horizontal member of the joint. The lengths in the present study were 10, 20, and 30 mm. It was found that joints manufactured from beech had the highest withdrawal force capacity; this trait was lowest in joints made from the light wood of poplar and fir. The glued-in length of the tenon exerted a significant influence on the withdrawal force capacity of the joints. The greatest withdrawal force capacity increment of M&LT T-type joints was obtained when the tenon length changed from 10 to 20 mm.

Key words: Furniture, loose tenon, tenon length, withdrawal force capacity, wood species

1. Introduction

Joints constitute the most sensitive element of furniture construction and for this reason continuous efforts are being made to find ways to increase their stiffness and strength (Eckelman 2003). Eckelman et al. (2002) determined the withdrawal and bending strength of dowel joints connecting elements made of plywood and oriented strand boards. Furthermore, the stiffness of round mortise and tenon joints (Haviarova et al. 2001a, 2001b; Eckelman et al. 2004, 2006a; Akcay et al. 2005) and their impact on improving the stiffness of a bookcase frame were investigated (Tankut et al. 2003, 2007). Further studies evaluated the influence of a change in tenon and mortise shapes on the withdrawal force capacity of mortise and tenon (M&T) joints (Akcay et al. 2005; Eckelman et al. 2006b). Abundant numerical analyses of M&T joints made it possible to optimize their shapes from the point of view of the highest wood strength and glue line (Smardzewski 1998, 2002; Smardzewski and Prekrat 2002; Smardzewski and Papuga 2004; Martinović et al. 2008). The impact of tenon dimensions on the strength of M&T joints was assessed in the laboratory by Wilczyński and Warmbier (2003). They demonstrated that the strength of examined joints depended, primarily, on the length of the tenon, whereas the stiffness of the joint depended on the tenon width. Mortise and loose tenon joints (M&LT), one of the most popular connections, are widely used to design furniture constructions where strong joints are required. M&LT joints can be made using simple machines and can even be constructed using hand drills if desired. This makes these joints attractive for use in developing nations (Aman et al. 2008). A decrease in the loss of materials is the most important advantage of M&LT joints in comparison with M&T joints. Other advantages of M&LT joints include a decrease in costs derived from using wood with smaller dimensions when the wood used is from an expensive species, decrease in joint production time, and depreciation of wood machines. The strength of M&LT joints falls somewhere between that of the dowel joint and the conventional M&T joint (Aman et al. 2008). The influence of the shape and dimensions of the tenon on the withdrawal force capacity of M&LT joints has not been previously determined.

The aim of this study was to determine the effect of wood species and loose tenon length on the withdrawal force capacity of M&LT T-type furniture joints.

2. Materials and methods

2.1. Test materials

Specimens were constructed of oak (O) (*Quercus alba*), beech (B) (*Fagus orientalis* L.), poplar (P) (*Populus deltoides*), sycamore (S) (*Platanus orientalis*), fir (F) (*Abies alba*), and white walnut (W) (*Juglans cinerea*). The loose

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tenons used in construction of joint specimens were made of beech (*Fagus orientalis* L.). The joint members were cut from straight grain wood that was free from defects and conditioned to nominal moisture content (12%). Shear strength parallel to the grain and specific gravity values of the woods were determined according to the principles of ASTM D-143 and ASTM D-2395, respectively (American Society of Testing and Materials 1999a, 1999b). Polyvinyl acetate adhesive (PVAc) with a solid content of 60%, density of 1.08 g cm^{-3}, and pH value of 5 was used to assemble the joint specimens.

2.2. Preparation of the specimens

Tests were performed on T-type joint specimens (Eckelman et al. 2002), and the shape and dimensions of the applied joints are presented in Figure 1. Using a face-milling cutter 8 mm in diameter, a mortise 30 mm wide and 38 mm deep was made in the vertical element. The same cutter was used to make mortises 30 mm wide and 10, 20, and 30 mm deep in the horizontal elements. The width of the loose tenon amounted to $30^{-0.1}$ mm, while its thickness was $8^{-0.1}$ mm. Depending on the depth at which the tenon was glued into the mortise of the horizontal element, its length was $48^{-0.25}$, $58^{-0.25}$, or $68^{-0.25}$ mm. The strength of the joint depended exclusively on the length glued in. That is why, in order to simplify the description further on in this paper, it was decided that the length of the tenon would refer to the length of its gluing into the horizontal element of the joint: 10, 20, or 30 mm. The tenon and the mortise were fitted in such a way that clearance between the bottom of the mortise and the base of the tenon did not exceed 0.125 mm, while clearance between the tenon and the side walls of the mortise was not greater than 0.05 mm. In order to isolate shoulders when assembling the joints, a piece of wax paper was inserted between the end of the load block and the face of the test block. PVAc adhesive was applied both to the mortise and the loose tenon, and the joints were assembled. Five specimens of each loose tenon length were constructed from each wood species. Joints were then clamped for 24 h while the glue line dried. A total of 90 T-type joint specimens (6 wood species × 3 loose tenon lengths × 5 replications) were prepared and tested (Table 1). The joints were kept in a climatic chamber at a relative humidity of 65 ± 3% and temperature of 20 ± 2 °C for 3 weeks before testing. After this period, in the presented environment (humidity and temperature), the moisture content of the wood is balanced at 12% so that the glue line achieves its full strength (Altinok et al. 2009; Maleki et al. 2012).

2.3. Method of testing

The specimens were subjected to uniaxial tension with a numerically controlled Instron 4486 testing machine, using appropriate equipment, as shown in Figure 2. The feeding velocity amounted to 5 mm min^{-1}. During the tests, the value of the force was recorded with an accuracy of 1 N. Experiments were terminated as soon as a rapid decline in the value of the force was observed, and the sample was destroyed. The failure modes of joints were also observed and recorded for each wood species after testing.

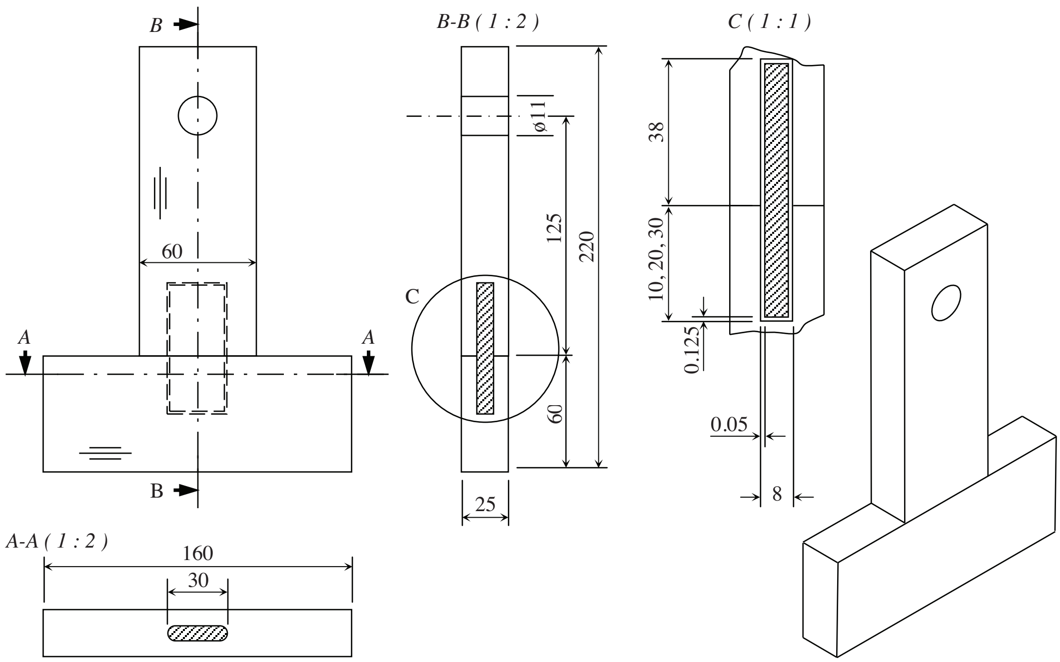

Figure 1. T-type joint specimens used in the study (measurements in millimeters).

Table 1. Symbols for joints based on length of loose tenon.

Type of wood	Length of loose tenon (mm)		
	10	20	30
	Symbols for joints based on length of loose tenon		
B - Beech	B1	B2	B3
W - Walnut	W1	W2	W3
F - Fir	F1	F2	F3
O - Oak	O1	O2	O3
S - Sycamore	S1	S2	S3
P - Poplar	P1	P2	P3

Figure 2. Loading method of joint specimens.

3. Results

Shear strength parallel to the grain and specific gravity values of the woods used in this study are presented in Table 2. In joints constructed of beech, in addition to the loose tenon being pulled out of the mortise, failure occurred mostly along the adhesive line between the surfaces of the loose tenon and the walls of the mortise. On the other hand, in 4 out of 15 poplar joints and 1 out of 3 joints constructed of fir, failures occurred in the test blocks apart from the adhesive line (Figure 3). This was also observed in 1 out of 15 walnut, 1 out of 5 sycamore, and 2 out of 15 oak specimens. The phenomenon was probably due to weak shear strength perpendicular to the grain of wood and may be good evidence for the effect of wood species on joint strength.

Tables 3, 4, and 5 present statistical analyses regarding the lack of significance in differences in withdrawal force capacity among M&LT T-type joints with tenon lengths of 10, 20, and 30 mm. The analysis was performed for dependent samples at $P < 0.05$ using Statistica v. 9.1 (StatSoft, Inc.). It is evident from Table 3 that for joints with tenons of 10 mm in length, 4 out of 15 pairs of joints failed to exhibit any significance of wood species impact on their withdrawal force capacity. In the case of joints with 20-mm tenons (Table 4), the same lack of the effect of wood species on withdrawal force capacity of the joints was found in 5 out of 15 pairs of joints, and in the case of 30-mm tenons, in 6 pairs of joints (Table 5). In all joint groups, no withdrawal force capacity differences were observed in specimens constructed of oak and walnut or walnut and sycamore (O1,2,3-W1,2,3; O1,2,3-S1,2,3). In addition, in groups of joints with 10-mm and 30-mm tenons, no significant differences in withdrawal force capacity of walnut and sycamore joints (W1,3-S1,3) were found; however, in groups of joints with 20-mm and 30-mm tenons, no significant differences in withdrawal force capacity were observed in joints constructed of beech and oak or beech and walnut (B2,3-O2,3; B2,3-W2,3). No statistically significant differences in withdrawal force

Table 2. Some physical and mechanical properties of woods used in the study.

Wood species	SG[a]	CV[b] (%)	Average shear strength[c] (MPa)	CV (%)
Beech	0.68	5.69	14.19	7.62
Walnut	0.69	5.57	12.86	8.95
Fir	0.42	12.60	7.07	10.10
Oak	0.70	5.30	13.53	7.11
Sycamore	0.57	8.34	10.47	13.27
Poplar	0.46	6.95	7.75	12.20

[a]Specific gravity of wood based on oven-dried weight and oven-dried volume (ASTM D-2395).
[b]Coefficient of variance.
[c]Measured values were determined according to ASTM D-143 standard at a nominal 12% moisture content.

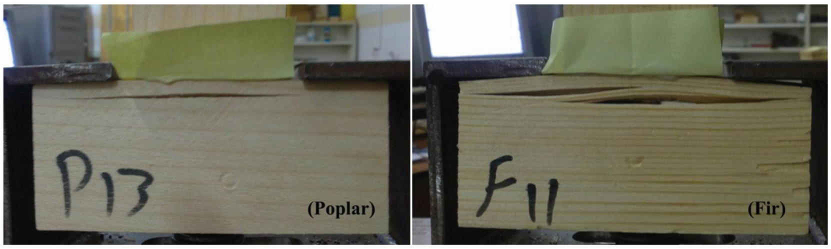

Figure 3. Modulus of failures of M&LT joint specimens made of poplar and fir.

capacity were determined in joints constructed of poplar and fir (P1-F1) for 10-mm tenons, in poplar and oak (P2-O2) for 20-mm tenons, and in beech and sycamore (B3-S3) for 30-mm tenons. In the remaining cases, significant differences were found in the withdrawal force capacity of tested joints depending on wood species. Further variability in joint withdrawal force capacity is presented in Figure 4.

Figure 4 (B1, O1, W1, S1, P1, F1) shows the withdrawal force capacity of M&LT joints with 10-mm tenons. It is clear from this figure that joints constructed of beech were characterized by the highest withdrawal force capacity (2.722 kN), whereas joints constructed of fir showed the worst withdrawal force capacity (1.503 kN). Furthermore, withdrawal force capacity measurement results for joints constructed of fir had the highest scatter around the mean value. Figure 4 (B2, O2, W2, S2, P2, F2) presents the withdrawal force capacity of M&LT joints with 20-mm tenons. It is clear that joints constructed of beech have the highest withdrawal force capacity (4.716 kN), while the poorest withdrawal force capacity was observed in joints constructed of fir (2.435 kN). It is also evident that the test results for joints constructed of oak and poplar had the highest scatter around mean values. Figure 4 (B3, O3, W3, S3, P3, F3) illustrates withdrawal force capacity of M&LT joints with 30-mm tenons. It is clear that joints constructed of beech (6.226 kN) as well as oak, walnut, and sycamore had the highest withdrawal force capacity. On the other hand, the lowest withdrawal force capacity was determined in joints constructed of fir (3.574 kN). In addition, the test results of joints constructed of poplar had the highest scatter around the mean value.

In Figure 5, the effect of tenon length on withdrawal force capacity of M&LT T-type furniture joints is presented

Table 3. T-test for dependent samples (joints with 10-mm tenons). Differences are not significant at P < 0.05.

Specimen	Average load (kN)	STD (kN)	Important	Difference	STD - difference	T	df	P	Confidence	
									–95.00%	+95.00%
O1	2.202	0.104								
W1	2.186	0.232	5	0.016	0.313	0.114	4	0.915	–0.373	0.405
O1	2.202	0.104								
S1	2.230	0.189	5	–0.028	0.262	–0.239	4	0.823	–0.353	0.297
W1	2.186	0.232								
O1	2.202	0.104	5	–0.016	0.313	–0.114	4	0.915	–0.405	0.373
W1	2.186	0.232								
S1	2.230	0.189	5	–0.044	0.173	–0.568	4	0.600	–0.259	0.171
S1	2.230	0.189								
O1	2.202	0.104	5	0.028	0.262	0.239	4	0.823	–0.297	0.353
S1	2.230	0.189								
W1	2.186	0.232	5	0.044	0.173	0.568	4	0.600	–0.171	0.259
P1	1.582	0.142								
F1	1.504	0.362	5	0.078	0.450	0.388	4	0.718	–0.480	0.636
F1	1.504	0.362								
P1	1.582	0.142	5	–0.078	0.450	–0.388	4	0.718	–0.636	0.480

Table 4. T-test for dependent samples (joints with 20-mm tenons). Differences are not significant at P < 0.05.

Specimen	Average load (kN)	STD (kN)	Important	Difference	STD - difference	t	df	P	Confidence	
									–95.00%	+95.00%
B2	4.716	0.190								
O2	4.382	0.411	5	0.334	0.409	1.825	4	0.142	–0.174	0.842
B2	4.716	0.190								
W2	4.628	0.296	5	0.088	0.330	0.596	4	0.583	–0.322	0.498
O2	4.382	0.411								
B2	4.716	0.190	5	–0.334	0.409	–1.825	4	0.142	–0.842	0.174
O2	4.382	0.411								
W2	4.628	0.296	5	–0.246	0.593	–0.927	4	0.406	–0.983	0.491
O2	4.382	0.411								
S2	4.204	0.221	5	0.178	0.561	0.710	4	0.517	–0.518	0.874
O2	4.382	0.411								
P2	3.602	0.424	5	0.780	0.724	2.407	4	0.074	–0.120	1.680
W2	4.628	0.296								
B2	4.716	0.190	5	–0.088	0.330	–0.596	4	0.583	–0.498	0.322
W2	4.628	0.296								
O2	4.382	0.411	5	0.246	0.593	0.927	4	0.406	–0.491	0.983
S2	4.204	0.221								
O2	4.382	0.411	5	–0.178	0.561	–0.710	4	0.517	–0.874	0.518
P2	3.602	0.424								
O2	4.382	0.411	5	–0.780	0.724	–2.407	4	0.074	–1.680	0.120

for each of the wood species utilized. A certain regularity is evident; an increase in tenon length caused a digressive increase in withdrawal force capacity in tested joints, with the exception of joints manufactured from fir (B–P, Figure 5). In the case of fir joints (F, Figure 5), this relationship was progressive. For joints constructed of beech (B, Figure 5), an increase in the tenon length from 10 to 20 mm caused an increase in joint withdrawal force capacity of approximately 73%, whereas increase in the tenon length from 20 to 30 mm resulted in an increase in joint withdrawal force capacity of 32%. Joints manufactured from oak increased withdrawal force capacity by 99% when tenon length was changed from 10 to 20 mm (O, Figure 5). Successive increases in tenon length from 20 to 30 mm improved the withdrawal force capacity of joints by 35%. Similar regularity was observed in joints constructed of walnut (W, Figure 5). The first tenon length increment improved the withdrawal force capacity of the joint by 111% and the successive increment by only 33%. For joints manufactured from sycamore (S, Figure 5) an increase in tenon length from 10 to 20 mm increased joint withdrawal force capacity by 88%, while an increase from 20 to 30 mm increased the joint withdrawal force capacity by 44%. Joints constructed of poplar increased in withdrawal force capacity by 128% following a change of tenon length from 10 to 20 mm (P, Figure 5). A further increase in the tenon length from 20 to 30 mm increased withdrawal force capacity of joints by only 33%. Joints manufactured from fir behaved differently (F, Figure 5). The first increase in tenon length caused a 48% improvement in joint withdrawal force capacity, while the next change in tenon length caused a 60% increase in joint withdrawal force capacity.

4. Discussion

It can be ascertained on the basis of the obtained research results that joints constructed of beech have the highest withdrawal force capacity, and this can be attributed to the high density of the wood species; beech also has the highest shear strength along fibers. Similar density and shear strength in walnut and oak led to the absence of significant differences in withdrawal force capacity of M&LT T-type joints. The absence of a significant difference in withdrawal force capacity in joints manufactured from oak and sycamore was surprising. These wood species differ significantly with respect to density and

Table 5. T-test for dependent samples (joints with 30 mm length tenons). Differences are not significant at P < 0.05.

Specimen	Average load (kN)	STD (kN)	Important	Difference	STD - difference	t	df	P	Confidence −95.00%	Confidence +95.00%
B3	6.224	0.291								
O3	5.914	0.196	5	0.310	0.472	1.469	4	0.216	−0.276	0.896
B3	6.224	0.291								
W3	6.140	0.434	5	0.084	0.694	0.271	4	0.800	−0.777	0.945
B3	6.224	0.291								
S3	6.040	0.144	5	0.184	0.365	1.127	4	0.323	−0.269	0.637
O3	5.914	0.196								
B3	6.224	0.291	5	−0.310	0.472	−1.469	4	0.216	−0.896	0.276
O3	5.914	0.196								
W3	6.140	0.434	5	−0.226	0.267	−1.893	4	0.131	−0.558	0.106
O3	5.914	0.196								
S3	6.040	0.144	5	−0.126	0.237	−1.187	4	0.301	−0.421	0.169
W3	6.140	0.434								
B3	6.224	0.291	5	−0.084	0.694	−0.271	4	0.800	−0.945	0.777
W3	6.140	0.434								
O3	5.914	0.196	5	0.226	0.267	1.893	4	0.131	−0.106	0.558
W3	6.140	0.434								
S3	6.040	0.144	5	0.100	0.402	0.556	4	0.608	−0.400	0.600
S3	6.040	0.144								
B3	6.224	0.291	5	−0.184	0.365	−1.127	4	0.323	−0.637	0.269
S3	6.040	0.144								
O3	5.914	0.196	5	0.126	0.237	1.187	4	0.301	−0.169	0.421
S3	6.040	0.144								
W3	6.140	0.434	5	−0.100	0.402	−0.556	4	0.608	−0.600	0.400

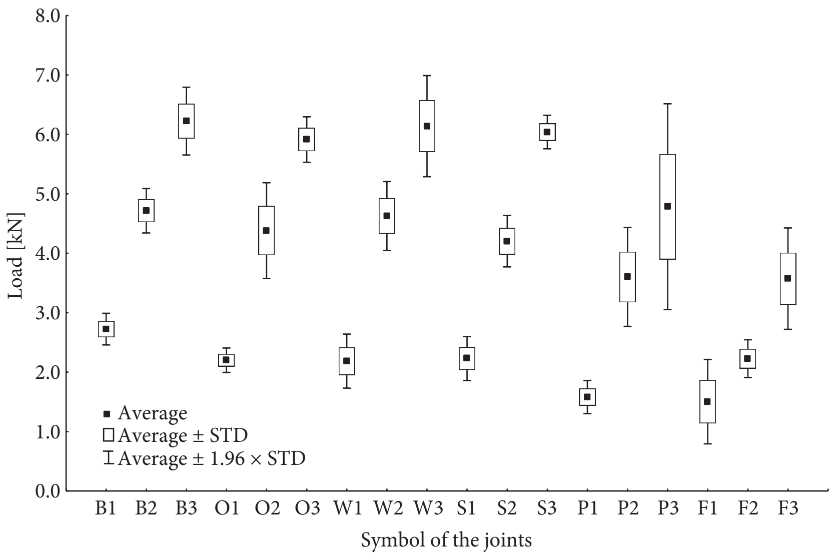

Figure 4. Impact of wood species on the withdrawal force capacity of M&LT T-type joints with 10, 20, and 30 mm length tenons.

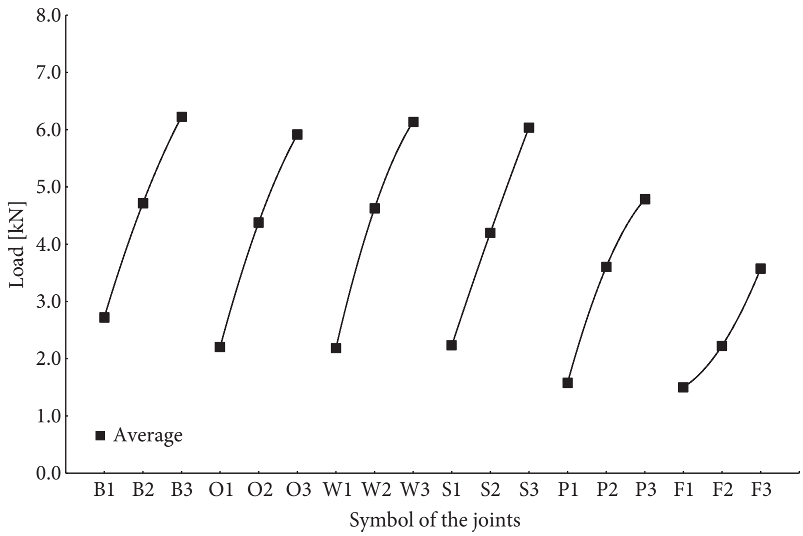

Figure 5. Impact of tenon length on the withdrawal force capacity of M&LT T-type joints manufactured of beech, oak, walnut, sycamore, poplar, and fir. B: $y = 0.25 + 0.272x - 0.0024x^2$, $x \in <10, 20, 30>$; O: $y = -0.63 + 0.315x - 0.0032x^2$, $x \in <10, 20, 30>$; W: $y = -1.19 + 0.384x - 0.0047x^2$, $x \in <10, 20, 30>$; S: $y = 0.12 + 0.218x - 0.0007x^2$, $x \in <10, 20, 30>$; P: $y = -1.28 + 0.328x - 0.0042x^2$, $x \in <10, 20, 30>$; F: $y = 1.40 + 0.021x + 0.0031x^2$, $x \in <10, 20, 30>$.

shear strength. The lowest withdrawal force capacity was determined in joints constructed of light wood: poplar and fir. In spite of similar physicomechanical properties, in the course of the experiments coniferous fir revealed a lower withdrawal force capacity in M&LT T-type joints than joints manufactured from the broad-leaved poplar. The length of the glued-in part of the tenon had a significant effect on the withdrawal force capacity of tested joints. The greatest withdrawal force capacity increment in M&LT T-type joints was obtained when tenon length was changed from 10 to 20 mm.

The aim of the study was to determine the effect of wood species and loose tenon length on withdrawal force capacity of M&LT T-type furniture joints. The specimens were manufactured from 6 different wood species, and the tenon lengths were 10, 20, and 30 mm. The analysis of research results revealed that:

1. Withdrawal force capacity of M&LT T-type furniture joints depended directly on loose tenon length and wood species.
2. M&LT T-type furniture joints constructed of beech were characterized by the highest withdrawal force capacity. This can be attributed to the high density of this wood species and the fact that it has the highest shear strength along fibers.
3. Joints constructed of fir had the worst withdrawal force capacity.
4. It was surprising to observe a lack of significant difference in withdrawal force capacity between joints manufactured from oak and sycamore.
5. Withdrawal force capacity of M&LT T-type furniture joints generally increased with loose tenon length for each wood species.
6. M&LT T-type furniture joints with 30-mm tenons had the highest withdrawal force capacity.
7. Joint members constructed from beech are recommended for use in the construction of M&LT T-type furniture joints with high withdrawal reactions.

References

Akcay H, Eckelman CA, Haviarova E (2005) Withdrawal, shear, and bending moment capacities of round mortise and tenon timber framing joints. For Prod J 55: 60–72.

Altinok M, Taş HH, Sancak E (2009) Load carrying capacity of spline joints as affected by board and adhesives type. Sci Res Essay 4: 479–473.

Aman RL, West HA, Cormier DR (2008) An evaluation of loose tenon joint strength. For Prod J 58: 61–64.

American Society of Testing and Materials (1999a) ASTM D-143. Standard Test Methods for Small Clear Specimens of Timber. American Society of Testing and Materials, West Conshohocken, PA, USA.

American Society of Testing and Materials (1999b) ASTM D-2395. Standard Test Methods for Specific Gravity of Wood and Wood-Based Materials. American Society of Testing and Materials, West Conshohocken, PA, USA.

Eckelman CA (2003) Textbook of Product Engineering and Strength Design of Furniture. Purdue University Press, West Lafayette, IN, USA.

Eckelman CA, Erdil Y, Haviarova E (2006a) Effect of shoulders on bending moment capacity of round mortise and tenon joints. For Prod J 56: 82–86.

Eckelman CA, Erdil Y, Zhang J (2002) Withdrawal and bending strength of dowel joints constructed of plywood and oriented strand board. For Prod J 52: 66–74.

Eckelman CA, Haviarova E, Akcay H (2006b) Exploratory study of the withdrawal resistance of round mortise and tenon joints with steel pipe cross pins. For Prod J 56: 55–61.

Eckelman CA, Haviarova E, Erdil YZ, Akcay H, Tankut A, Denizli N (2004) Bending moment capacity of round mortise and tenon furniture joints. For Prod J 54: 192–197.

Haviarova E, Eckelman CA, Erdil YZ (2001a) Design and testing of wood school desk frames suitable for production by low technology methods from waste wood residues. For Prod J 51: 79–88.

Haviarova E, Eckelman CA, Erdil YZ (2001b) Design and testing of environmentally friendly wood school chairs for developing countries. For Prod J 51: 58–64.

Maleki S, Derikvand M, Dalvand M, Ebrahimi GH (2012) Load carrying capacity of mitered furniture corner joints with dovetail keys under diagonal tension load. Turk J Agric For 36: 636–643.

Martinović D, Horman I, Hajdarević S (2008) Stress distribution in wooden corner joints (Raspodjela naprezanja u drvenim kutnim spojevima). Strojarstvo 50: 193–204 (in Croatian).

Smardzewski J (1998) Numerical analysis of furniture constructions. Wood Sci Technol 32: 273–286.

Smardzewski J (2002) Strength of profile-adhesive joints. Wood Sci Technol 36: 173–183.

Smardzewski J, Papuga T (2004) Stress distribution in angle joints of skeleton furniture. Electronic Journal of Polish Agricultural Universities, Wood Technology, Volume 7.

Smardzewski J, Prekrat S (2002) Stress distribution in disconnected furniture joints. Electronic Journal of Polish Agricultural Universities, Wood Technology, Volume 5.

Tankut A, Denizli-Tankut N, Gibson H, Eckelman CA (2003) Design and testing of bookcase frames constructed with round mortise and tenon joints. For Prod J 53: 80–86.

Tankut AN, Tankut N, Eckelman CA (2007) Design and testing of wall cabinet frames constructed with round mortise-and-tenon joints. For Prod J 57: 18–22.

Wilczyński A, Warmbier K (2003) Effect of joint dimensions on strength and stiffness of tenon joints. Folia Forestalia Polonica, Seria B, 34: 53–66.