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EFFECTS OF WOOD SPECIES AND JOINT TYPE ON BENDING MOMENT CAPACITY OF T-SHAPED FURNITURE JOINTS

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Abstract:
The objective of this study was to discover the effects of wood species and joint type on the bending moment capacity of t-shaped furniture joints made of white oak and red oak. Joints are the weakest part of furniture construction; therefore, it is imperative to determine the joints' durability, reliability, and strength depending on the joint type and wood species before the final application. Mortise&tenon and dowel joint types are the most commonly used alternatives in furniture construction, while white oak and red oak species are the most preferred species by the furniture industry. As per the study objectives, twenty T-shaped mortise&tenon and dowel joints made of white oak and red oak were prepared and subjected to statically vertical load to determine their bending moment capacity. The data collected across all sample groups were also checked for statistical significance through Two-way ANOVA analysis and Tukey pair-wise comparisons. Mortise&tenon joints made of white oak wood had the highest average bending moment capacity with a value of 436.71 N.m. The lowest average bending moment capacity, 227.38 N.m., was recorded for the sub-group containing dowel joints made of red oak. Overall, mortise&tenon joints had greater strength than dowel joints, and joints made of white oak also outperformed their red oak counterparts. There was no statistical difference between the average bending moment capacity of dowel joints made of white oak and red oak. The study showed that both the wood species and joint type significantly impacted the bending moment capacity of furniture joints; however, the joint type was a more decisive factor. This study was expected to be a good guide and serve as a valuable reference source for professionals and academics interested in researching furniture joints and construction.

Key words: *bending moment capacity; dowel joint; Mortise&tenon joint; red oak; white oak.*

INTRODUCTION

Joints are the weakest component of furniture construction because most of the failure occurs owing to fractured or loose joints rather than a failure on legs or rails (Eckelman 2003, Eckelman and Haviarova 2006, Smardzewski 2009). Therefore, it is significant to design joints that can resist subjected loads. The bending moment is one of the internal loads imposed on a rail, joint or post in furniture construction and is more significant than shear and axial loads. A joint could be designed if its bending moment capacity is known (Eckelman et al. 2016). Therefore, this study examined the bending moment capacity (BMC) of the joints.

Mortise&tenon (MT) and dowel joints are the most common joint types used in furniture construction due to their higher strength and stiffness as is frame timber constructions (Eckelman and Haviarova 2011). Moreover, dowel joints preferred favorable cost and production characteristics while MT joints were preferred for better performance. In a structural analysis of MT joints, if the wood along the neutral axis of the tenon is removed, two square-shaped tenons are obtained and it behaves like dowel joints. By using these behaviors, the BMC of MT joints could be estimated with parameters of wood species, tenon length and width, adhesive type and fitting tolerances (Eckelman 2003).

Awareness of furniture strength design in the mid-1940s increased studies related to furniture joints. Eckelman (1969) studied the effect of rail width and dowel spacing for dowel joints. Joint strength increased with wider rails and longer dowel spacing. Besides, an equation was obtained to predict BMC concerning dowel spacing and rail width. Hill and Eckelman (1973) studied the flexibility and bending strength of MT joints. Eckelman (1979) studied the in-plane and out-of-plane strength of T-shaped dowel joints made of black walnut considering open joint and rail thickness. Results showed that joints had lower strength and flexibility with increasing gaps between rail and post, while the increase in rail thickness joints had higher strength and flexibility. Shoulder effects significantly affect joint strength and flexibility because the bottom of

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the rails could resist higher compression strength. Zhang and Eckelman (1993) examined the effects of the number of dowels and dowel spacing for corner joints in case construction. The bending strength of the joints significantly increased as the number of dowels increased and the dowel spacing got narrower. Since the bending moment on the joint was distributed to dowels, the effective total cross-section area of dowels to resist internal forces increased. Thus, lower bending stress occurred on the dowel, which could endure longer under imposed loads. Besides, Derikvand and Ebrahimi (2015) studied the strength of dowel joints as a function of the number of dowels, dowel spacing, dowel size, and joint design. The density of the material used in furniture members and the embedment of dowels to each member affected joints' strength because dowel holding strength increased as a function of higher density and longer embedment (Erdil and Eckelman 2001, Eckelman et al. 2002, Zhang et al. 2001).

Tolerances between tenons and mortises had a significant effect due to the thickness of the glue line. Failure on joints first occurs on the glue line, and then, joint strength depends on the compression strength of the wood material. Hence, joints should be constructed with perfect fitting between mortise and tenon to increase their strength (Smardzewski 2002, Ratnasingam and Ioras 2013). In addition, wood species had a significant effect on MT joints due to the modulus of rupture of wood, which is one of the critical factors for fractured joints (Ratnasingam et al. 2010). Characteristics such as longer tenon, wider tenon, and wider rail on joint increase joint strength because longer tenon prevents withdrawal of tenon from mortises, wider tenons increase the effective cross-section area of the tenon and reduce bending stress on the tenon neck. Wider rails result in larger shoulder effects; therefore, the bottom edge of rails could resist higher compression stress due to bending (Erdil et al. 2005, Eckelman and Haviarova 2008, Derikvand et al. 2014, Oktaee et al. 2014, Zaborsky et al. 2018, Hu et al. 2018). Effective cross-section area results in bending stress distribution on the tenon cross-section, increasing joint strength (Tankut and Tankut, 2005, Likos et al. 2012, Likos et al. 2013, Zaborsky et al. 2017). Non-glued round MT joints with cross-pin could resist imposed load as much as those of glued joints because joint strength firstly depends on the shear strength of the glue line and then its bending strength. Similarly, round MT joints with cross-pin also depend on the shear strength of the pin (double-shear) and its bending strength (Eckelman et al. 2006, Uysal et al. 2015). Also, Podlena and Boruvka (2016) showed that the width of the annual ring on tenons affected joint strength.

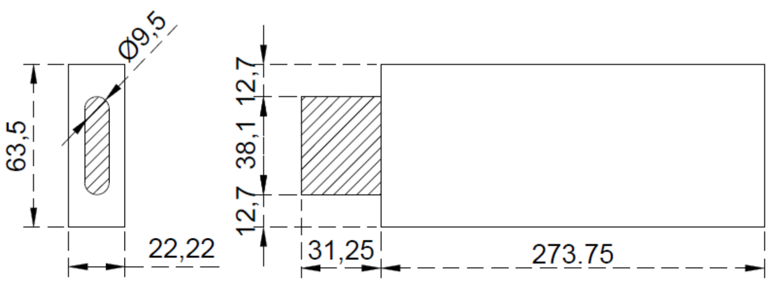
OBJECTIVE

This study aimed to discover the effects of wood species and joint type on the bending moment capacity of t-shaped furniture joints made of white oak and red oak. In order to achieve the study objective, the specimens were subjected to statically vertical load to determine BMC of T-shaped joints through data obtained from ultimate failure loads. Then, the effects of wood species and joint types on the BMC of joints were examined statistically.

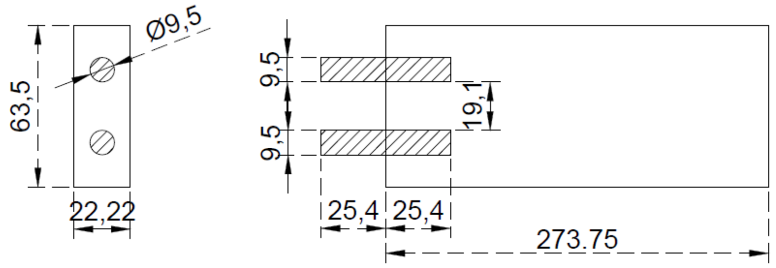
MATERIALS AND METHODS

In this study, white oak (*Quercus alba*) and red oak (*Quercus rubra*) species, widely used in furniture construction, were utilized to construct T-shaped MT and dowel joints. All defect-free rails and posts of joints were processed to a thickness of 22.22mm, a width of 63.50mm and a length of 273.75mm but the length of rails for MT joints was 305mm.

Tenons were cut with the help of a tenoning machine to a dimension of 9.50 x 31.75 x 38.10mm (Fig. 1.a). Matching mortises were cut on a multi-chisel router. The face of the tenons and the wall of the mortises were coated with polyvinyl acetate (PVA) adhesive and remained clamped for at least 8 hours for proper curing. Dowels 9.50mm in diameter and 50.80mm in length made of white oak were used to construct dowel joints (Fig. 1.b). Dowel holes and surface of dowels were coated with PVA adhesive, and specimens remained clamped for at least 8 hours for proper curing. All specimens were conditioned at room temperature at 7% moisture content for at least one week. A total of 20 samples, 5 for each sub-group, were obtained for the study.



a.



b.

Fig. 1.
Configuration of joints
a. - MT joint; b. - Dowel joint.

All tests were conducted on a Universal Test Machine with a load capacity of 4450N. The edgewise vertical static load was applied on the rail with a 254mm-long moment arm with a rate of 12.7mm/min (Fig. 2). All tests were continued until non-recoverable failures occurred on joints (Erdil *et al.* 2005). Ultimate failure load was obtained from tests and BMC of the joints was determined by;

$$M = F_{ult} \times l \tag{1}$$

where: M is bending moment, in N.m;
F_{ult} is ultimate failure load, in N;
l is moment arm, in m.

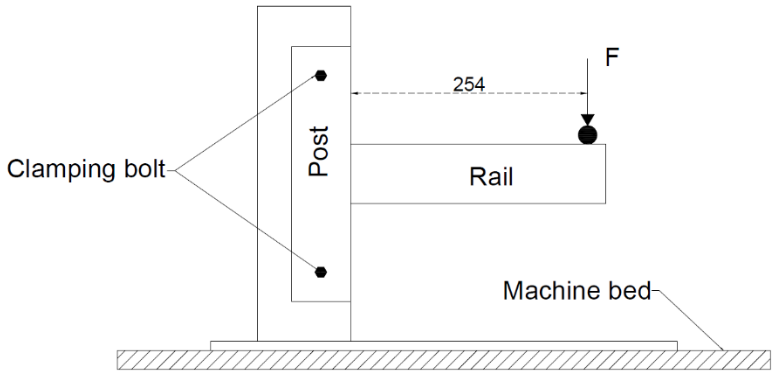


Fig. 2.
Joint test configuration.

Last but not the least, data collected for all sample groups were checked for the presence of statistical significance through Two-way ANOVA analysis and Tukey pair-wise comparisons carried out in Minitab Statistical Analyses Software. The effects of independent variables on dependent variables were also evaluated through interaction and main effect plots.

RESULTS AND DISCUSSION

Results for bending moment capacities of T-shaped MT and dowel joints made of both white oak and red oak were given in Table 1 and Fig. 3. According to tests results, MT joints made of white oak had the highest average BMC (436.71 N.m) with a standard deviation of 28.3 N.m. The average BMC of dowel joint made of white oak was 222.53 N.m with a standard deviation of 49.63 N.m. Those of MT joint made of red oak was 310.27 N.m with a standard deviation of 24.11 N.m. Dowel joints made of red oak had a BMC of 227.38 N.m with a standard deviation of 22.20 N.m. Results showed that MT joints were stronger than dowel joints because both were imposed in-plane loading and had identical cross-sections of rails, but the effective cross-section area of MT joints that resisted bending stress was larger than those of dowel joints. Therefore, failures occurred at a lower strength for dowel joints compared to MT joints. It can be easily seen that white oak joints performed better than red oak ones because failure on tenon depends on the modulus of rupture (MoR) of wood material, and MoR of white oak was greater than the MoR of red oak. Moreover, a past study discovered that BMC for chair constructions with MT and dowel joints also had similar results: MT joints were 49% greater than dowel joints (Uysal *et al.* 2015). Similarly, in another past study, BMCs of MT and dowel joints were found to be 370.60 N.m and 276.60 N.m for plywood material and 125.40 N.m and 115.90 N.m for MDF material, respectively (Uysal *et al.* 2019).

Furthermore, authors of a past study documented that the BMC of T-shaped MT joints made of white oak (357.90 N.m) was higher than those of red oak (353.20 N.m) (Eckelman *et al.* 2016). In a previous study, BMCs of T-shaped dowel joints made of white oak and red oak were 249.02 N.m and 231.85 N.m, respectively (Uysal and Haviarova, 2018). As can be interpreted, the literature also supports this study's test results, which documented that MT joints performed better than dowel joints and joints made of white oak also had higher strength than those of red oak.

Table 1

Test results of BMC of T-shaped MT and dowel joints made of white oak and red oak

Wood Species	White Oak		Red Oak	
Joint Type	MT	Dowel	MT	Dowel
Sample 1	486.98	233.83	335.60	239.28
Sample 2	417.67	242.80	321.01	227.71
Sample 3	433.02	210.95	272.93	188.85
Sample 4	417.25	279.56	301.61	240.86
Sample 5	428.63	145.54	320.20	240.18
Average	436.71	222.53	310.27	227.38
Std Dev	28.93	49.63	24.11	22.20
CoV*	6.62%	22.30%	7.77%	9.76%

*CoV: Coefficient of Variation

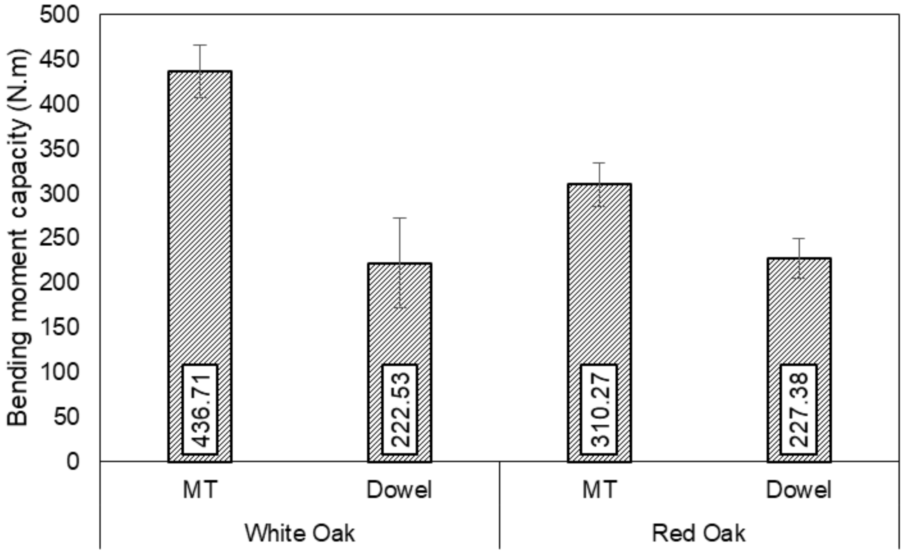


Fig. 3.
Average BMCs of T-shaped MT and dowel joints made of white oak and red oak.

Two-way ANOVA was performed to examine the significance of the effect of wood species and joint types on BMC of T-shaped furniture joints ($\alpha = 0.05$). Tukey pair-wise comparison analysis was also conducted to observe whether there is a statistically significant difference among sample groups at a 95% confidence level. Based on the results, wood species (p-value= 0.001), joint type (p-value < 0.001), and interaction term of wood species and joint type (p-value < 0.001) factors had a significant impact on the bending moment capacity of joints, as shown in Table 2. Wood species and joint type explained 89.58% of the variation in the bending moment capacity of joints. Moreover, the average BMC of MT joints made of white oak and red oak were significantly different, whereas there was no evidence to prove the statistically significant difference between the average BMC values of dowel joints made of red oak and white oak (Table 3). Moreover, these statistical interpretations can be clearly observed from interaction plot (Fig. 4) and the main effect plot (Fig. 5) created for the illustration of factor interactions and effects of factors for various levels, respectively.

Table 2

ANOVA for effect of wood species and joint types on BMC of T-shaped furniture joints

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Wood Species	1	18482	18482	16.90	0.001
Joint Type	1	110313	110313	100.88	<0.001
Wood Species*Joint Type	1	21544	21544	19.70	<0.001
Error	16	17496	1093		
Total	19	167835			

Model Summary			
S	R-sq	R-sq(adj)	R-sq(pred)
33.0678	89.58%	87.62%	83.71%

Table 3

Tukey pair-wise comparisons: Effect of wood species and joint types on BMC of T-shaped furniture joints (95% confidence)

Densification	N	Mean	Grouping		
White oak-MT	5	436.71	A		
Red oak-MT	5	310.27		B	
White oak-Dowel	5	227.38			C
Red oak-Dowel	5	222.53			C

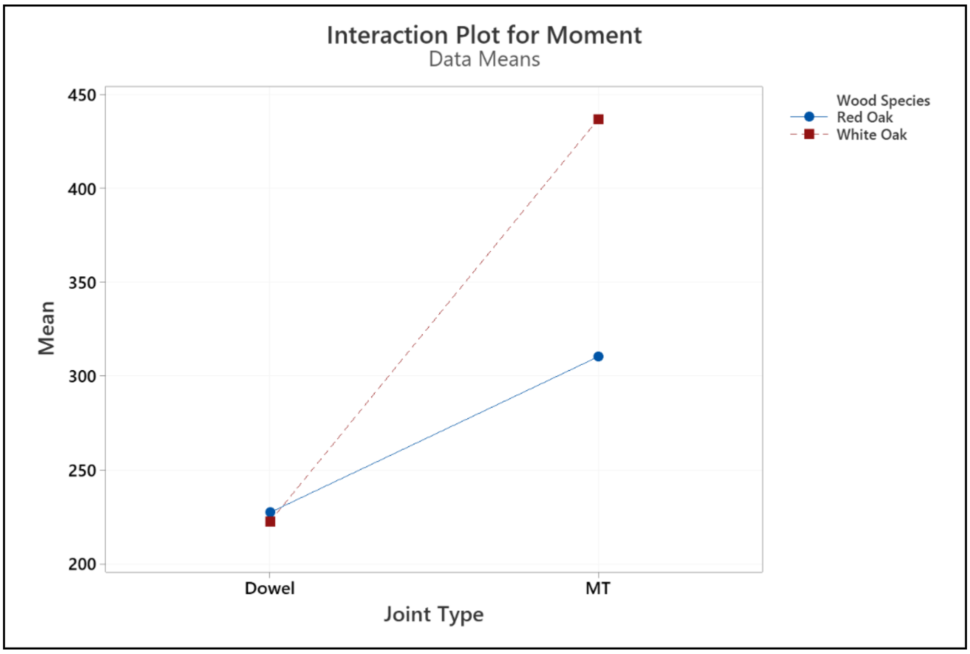


Fig. 4.
Interaction plot for BMC of joints.

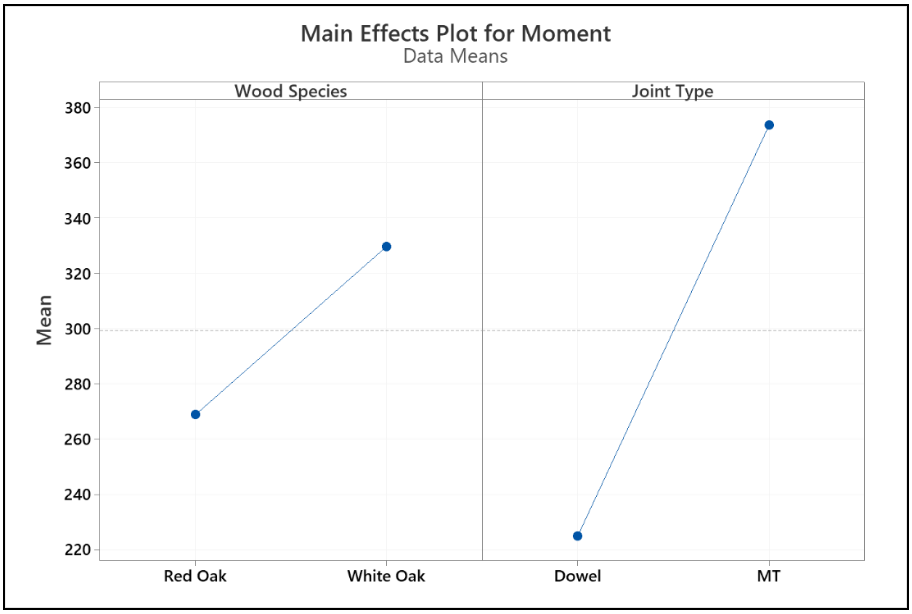


Fig. 5.
Main effects plot for BMC of joints.

As seen from the interaction plot in Fig. 4, the average BMC level for the white oak MT joints was way higher than that of the red oak MT joints. No such difference was observed for dowel joints across the wood species. The main effects plot also showed that joint type was a more decisive factor than the wood species based on the overall average BMC values since the range between the average BMC values of dowel and MT joints was much larger than that of the average BMC values of red oak and white oak joints as shown in Fig. 5.

CONCLUSION

This study investigated the BMC of T-shaped MT and dowel joints made of white oak and red oak. Based on the study's findings, it can be concluded that both factors, namely, wood species and the joint type were decisive factors for BMC performance of the joints. Moreover, MT joints made of white oak outperformed their counterparts made of red oak in terms of BMC. No meaningful differences were observed for BMC performance of the dowel joints made of white oak and red oak. Furthermore, joint type was determined to be more impactful on BMC of furniture joints when compared to the impact of wood species. Therefore, in the design of furniture construction, its structural analysis should be considered, and appropriate wood species and joint types should be used to obtain durable, reliable and strong constructions. Future research directions in this research stream could be (1) evaluating BMC performance of some other wood species commonly used in furniture construction, (2) constructing different unique joint types from white oak and red oak to further evaluate the impact of main factors on BMC performance, and (3) considering the use of a different type of glue and investigating the impact of glue type on BMC performance along with the factors of wood species and joint type. The limitation of this study was its relatively smaller sample size across comparison groups due to some resource unavailability. Even though this study had some limitations, it could still be a good guide and serve as a valuable reference source for professionals and academics interested in researching furniture joints.

REFERENCES

Derikvand M, Ebrahimi G, Eckelman CA (2014) Bending moment capacity of mortise andloose-tenon joints. Wood Fiber Sci. 46(2):159-166.

Derikvand M, Ebrahimi G (2015) Rotational stiffness of L-shaped dowel. Proc. 27th International Conference, Research of Furniture Industry, Ankara (Turkey), pp. 18-27.

Eckelman CA (1969) Engineering concept of single-pin dowel joint design. Forest Products Journal 19(12):52-60.

Eckelman CA, Erdil YZ, Zhang J (2002) Withdrawal and bending strength of dowle joints constructed of plywood and oriented stranboard. Forest Products Journal 52(9):66-74.

Eckelman CA (2003) Textbook of product engineering and strength design of furniture. Purdue University, WestLafayette, IN.

Eckelman CA, Erdil YZ, Haviarova E (2006) Effect of shoulders on bending moment capacity of round mortise and tenon joints. For Prod J 56(1):82-86.

Eckelman CA, Haviarova E (2008) Rectangular mortise and tenon semi-rigid joint connection factors, For. Prod. J. 58(12):49-58.

Eckelman CA, Haviarova E (2011) Rectangular mortise and full-width tenon joints in ready-to-assemble light-frame timber constructions. Wood and Fiber Science 46(4):346-352.

Eckelman CA, Uysal M, Haviarova E (2016) Statisticallower tolerance limits for rectangular mortise and tenon joints. BioResources 11(3):7162-7171.

Erdil YZ, Eckelman CA (2001) Withdrawal strength of dowels in plywood and Oriented Strand Board. Turkish Journal of Agriculture and Forestry 25:319-327.

Erdil YZ, Kasal A, Eckelman CA (2005) Bending moment capacity of rectangular mortise and tenon furniture joints.For Prod J 55(12):209-213.

Hill MD, Eckelman CA (1973) Flexibility and bending strength of mortise and tenon joints. Furniture Design &Manufacturing, pp. 1–8.

Hu W, Fu W, Guan H (2018) Optimal Design of Stretchers Positions. Wood Research 63(3):505-516.

Kasal A, Eckelman CA, Haviarova E, Erdil YZ, Yalcin I (2015) Bending moment capacities of L-shaped mortise and tenon joints under compression and tension loadings. BioResources 10(4):7009-7020.

Likos E, Haviarova E, Eckelman CA, Erdil YZ, Ozcifci A (2012) Effect of tenon geometry, grain orientation, and shoulder on bending moment capacity and moment rotation characteristics of mortise and tenon joints. Wood Fiber Sci 44(4):462-469.

Likos E, Haviarova E., Eckelman CA, Erdil YZ, Ozciftci A (2013) Technical note: Static versus cyclic load capacity of side chairs constructed with mortise and tenon joints. Wood and Fiber Science 45(2):223-227.

Oktaee J, Ebrahimi G, Layeghi M, Derikvand M and Eckelman CA (2014) Bending moment capacity of simple and haunched mortise and tenon furniture joints under tension and compression loads. Turkish Journal of Agriculture and Forestry 38(2):291-297.

Podlena M, Boruvka V 2016 Stiffness coefficients of mortise and tenon joints used on wood window profiles. BioResources 11(2):4677-4687. DOI: 10.15376/biores311.2.4677-4687

Ratnasingam J, Ioras F, McNulty T 2010 Fatigue strength of mortise and tenon furniture joints made from oil palm lumber and some Malaysian timbers Journal of Applied Sciences 10(22):2869-2874.

Ratnasingam J, Ioras F (2013) Effect of adhesive type and glue-line thickness on the fatigue strength of mortise and tenon furniture joints. European Journal of Wood and Wood Products 71(6):819-821.

Smardzewski J (2002) Strength of profile-adhesive joints. Wood Science and Technology 36:173-183

Smardzewski J (2009) The reliability of joints and cabinet furniture. Wood Research 54(1):1-10.

Tankut AN, Tankut N (2005) The effects of joints forms (shape) and dimensions on the strength of mortise and tenon joints. Turkish Journal of Agriculture and Forestry 29:493-498.

Uysal M, Haviarova E (2018) Estimating design values for two-pin moment resisting dowel joints with lower tolerance limit approach. BioResources 13(3):5241-5253.

Uysal M, Tasdemir C, Haviaroava e, Gazo R (2019) Manufacturing Feasibility Analysis and Load Carrying Capacity of Computer Numerical Control Cut Joints with Interlocking Assembly Feature. Bioresources 14(1):1525-1544.

Zaborsky V, Boruvka V, Ruman D, Gaff M (2017) Effects of Geometric Parameters of Structural Elements on Joint Stiffness. Bioresources 12(1):932-946.

Zaborsky V, Sikora A, Gaff M, Kasikova V, Boruvka V (2018) The Effect of Selected Factors on Domino Joint Stiffness. Bioresources 13(3):5416-5431.

Zhang J, Eckelman CA (1993) Rational design of multi-dowel corner joints in case construction. Forest Products Journal 43(11/12):52-58.

Zhang J, Quin F, Tackett B (2001) Bending fatigue life of two-pin dowel joints constructed of wood and wood composites. Forest Products Journal 51(10):73-78.