AN INVESTIGATION ON THE EFFECTS OF WOOD SPECIES OF DOWELS AND THE END DISTANCE OF CATCH CONNECTORS (CLAMEX P14) ON THE BENDING MOMENT OF L-TYPE CORNER JOINTS FOR RTA (READY-TO-ASSEMBLE) FURNITURES[1]

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Abstract. In this study, the effects of the wood species of dowels and the end distance were examined relative to the moment resistance of L-type corner joints with catch connector (Clamex P14) under compression loads. Melamine-coated medium-density fiberboards, catch connector (Clamex P14), and three different wood species of dowels were used as specimen (as used in the furniture industry). L–type joint specimens 297 mm long were tested under static diagonal compression loads for determining the bending moment capacity. The results showed that the Orientalis beech dowel had the highest bending moment resistance under compression. Regarding the end distance, the highest bending moment resistance was obtained from an end distance of 60 mm.

Keywords: Bending moment resistance, corner joint, end distance, catch connector (Clamex P14), nonglued wooden dowel.

INTRODUCTION

Case furniture is one of the most important furniture produced and used today. It is used extensively in homes and offices for storage and has become essential in maintaining order in both settings (Ho and Eckelman 1994). Medium-density fiberboard (MDF) and particleboard (PB) are the most common wood-based panel products used in the construction of case furniture. Ready-to-assemble (RTA)-type fasteners are commonly used to construct joints in case furniture. Fasteners for furniture have been developed and used for almost half a century. There are numerous types of RTA connectors (Zhang et al 2005).

The following properties were taken into consideration during the selection of joints: functionality, technical-aesthetic, technological quality, and strength. Catch connector (Clamex P14) includes solutions in which immobilization of elements and its pressure is achieved by turning an appropriate coupler, resulting in a mounting load. Usually, joints are separable and partially visible externally. Furthermore, it guarantees stable assembly when repeated assembly and disassembly are necessary (Podskarbi et al 2016). For the catch connector–based (Clamex P14) constructions, two connectors are placed near the ends of the members which are to be connected, and this provides plastic or mechanical strength with intermediate unglued dowels spaced along the edge of the members to help locate and permanently position them. To obtain a visually tight closing of the ends of the joints, it is important to locate the connectors near the ends of the members. Placing the catch connector (Clamex P14) too close to the ends, however, can seriously affect the structural integrity of the joint. Therefore, it is important to determine the minimum end distance for the placement which will allow the development of maximum joint strength.

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Researchers have carried out several studies related to end distances. Rajak (1989) found out that to prevent end splits from occurring when screws are inserted into pilot holes, 5-mm screws should be located at least 25 mm from the end of the board, 5.5-mm screws no less than 37 mm, and 6-mm screws no less than 50 mm. Ho and Eckelman (1994) stated that the maximum racking resistance was obtained with a screw spacing of 75-90 mm. Liu and Eckelman (1998) discussed that the strength usually declined when the distance between the joint components was lower than approximately 57 mm.

Simek at al. (2010) investigated the effects of the end distance of cam-lock RTA fasteners and nonglued wooden dowels on the splitting and bending moment resistance, and dowel number of RTA corner joints. The results showed that for a joint length of 760 mm, the dowels significantly supported the cam connectors. In addition, two cam fasteners along with three, four, or five unglued dowels increased the bending moment capacity in proportion to the increasing number of unglued dowels. Moreover, researchers have conducted several studies related to dowel spacing. Zhang and Eckelman (1993a, 1993b) determined that as the dowel diameter and dowel length were increased in PBs produced with a single-dowel at-pack corner joining element, their resistance increased as well. In other cases where a different number of dowels were used, the distance between the two dowels was to be 7.5 cm for the highest strength.

Norvydas et al (2005) have analyzed the effects of dowel spacing (32, 64, 96, 128, and 160 mm) and the nominal distance of dowels (20, 25, 30, 35, 40, 45, 50, 55, and 60 mm). They have stated that both the dowel spacing and the nominal distance of dowels significantly affected the joint resistance. Tankut (2005) determined that the maximum moment under compression and tension loads was obtained in 32 mm case construction joints when the spacing between dowels was at least 96 mm. Yerlikaya (2014) stated that the optimum dowel spacing was 96 mm in melamine impregnated paper coated medium-density

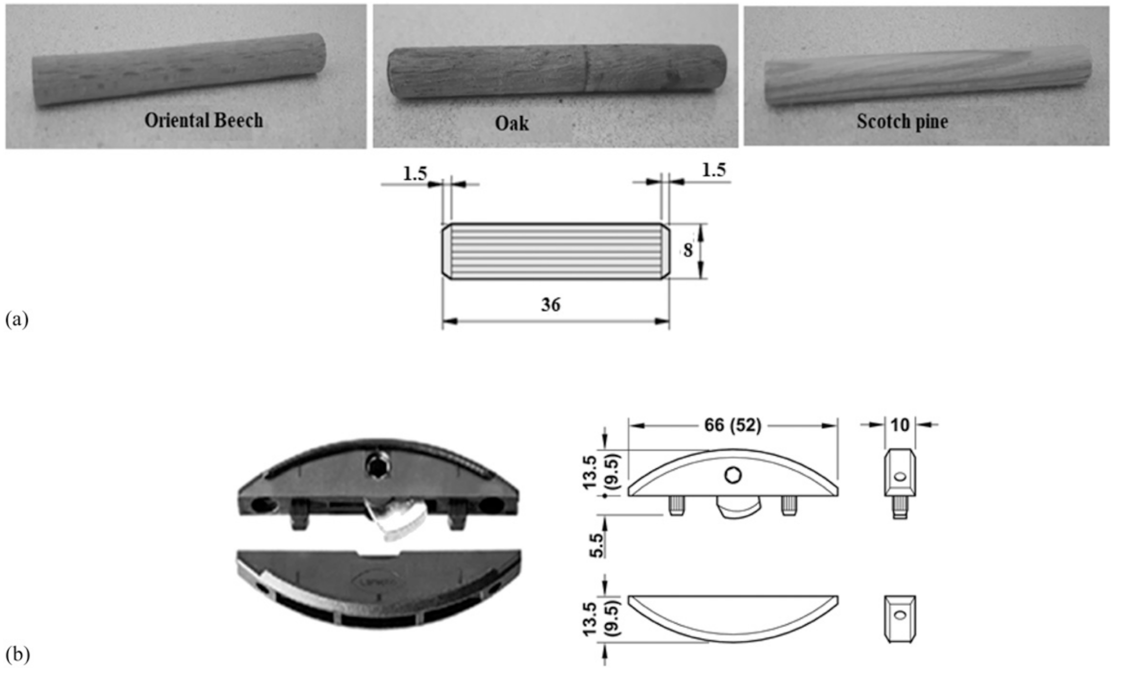

Figure 1. Wooden dowel species (a) and catch connector (Clamex P14) (b) (dimensions in mm).

Table 1. Combinations of test variables in the study.

Exp. No	The end distances (3 levels)	Wood species of dowel (4 levels)	Replicates
1	50 mm	Control (nondowel)	10
	50 mm	Orientalis beech	10
	50 mm	Oak	10
	50 mm	Scotch pine	10
2	60 mm	Control (nondowel)	10
	60 mm	Orientalis beech	10
	60 mm	Oak	10
	60 mm	Scotch pine	10
3	70 mm	Control (nondowel)	10
	70 mm	Orientalis beech	10
	70 mm	Oak	10
	70 mm	Scotch pine	10
Total			120 specimens

fiberboard (LMDF) and 128 mm in melamine impregnated paper coated particleboard (LPB). She explained that the joints with 32 and 64 mm dowel spacing had less strength than the joints with 96 and 128 mm dowel spacing. She indicated that LMDF corner joints were stronger than LPB corner joints. In their research, Saar et al (2015) tested connecting fittings of different type under failure loads. The results showed that the Invis Mx (Lamello AG Company, Bubendorf, Switzerland) had the highest average strength value in tensile test and Minifix (Lamello AG Company, Bubendorf, Switzerland) with beech dowel in shear test.

There are other investigations on RTA fastener joint strength such as those of Smardzewski and Prekrad (2002), Tankut (2006), Podskarbi and Smardzewski (2019), and Smardzewski and Prekrad (2020), but in general, their researches were not conducted to specifically determine the effect of the edge distance on joint strength or the extent to which the load capacity of the cam fasteners is augmented by the use of positioning dowels.

Hypothesis of this Research

1. H0: There is a significant relationship between dowels produced from three different wood species and the end distance of catch connectors (Clamex P14) on the bending moment resistance of L-type corner joints under diagonal compression.
2. H1: There is no significant relationship between dowels produced from three different wood species and the end distance of catch connectors (Clamex P14) on the bending moment resistance of L-type corner joints under diagonal compression. If p-value is 0.05, do not reject H0.

The object of this study is to investigate the effects of different wood species of dowels and the end distance of catch connectors (Clamex P14) on the bending moment resistance of L-type corner joints under diagonal compression. It is thought that as there is an insufficient number of studies in the literature on catch connectors (Clamex P14) which are new to the furniture industry, this study will be beneficial for the users of catch connectors

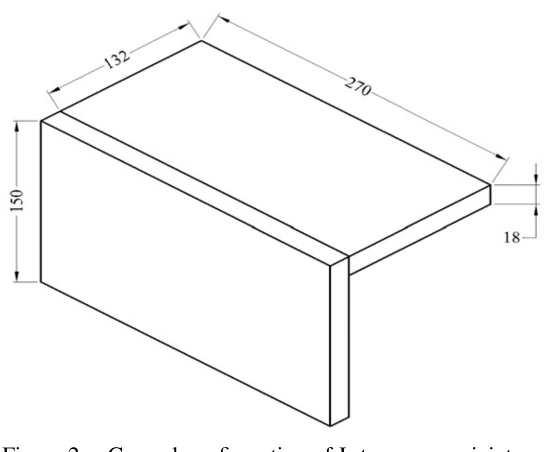

Figure 2. General configuration of L-type corner joints.

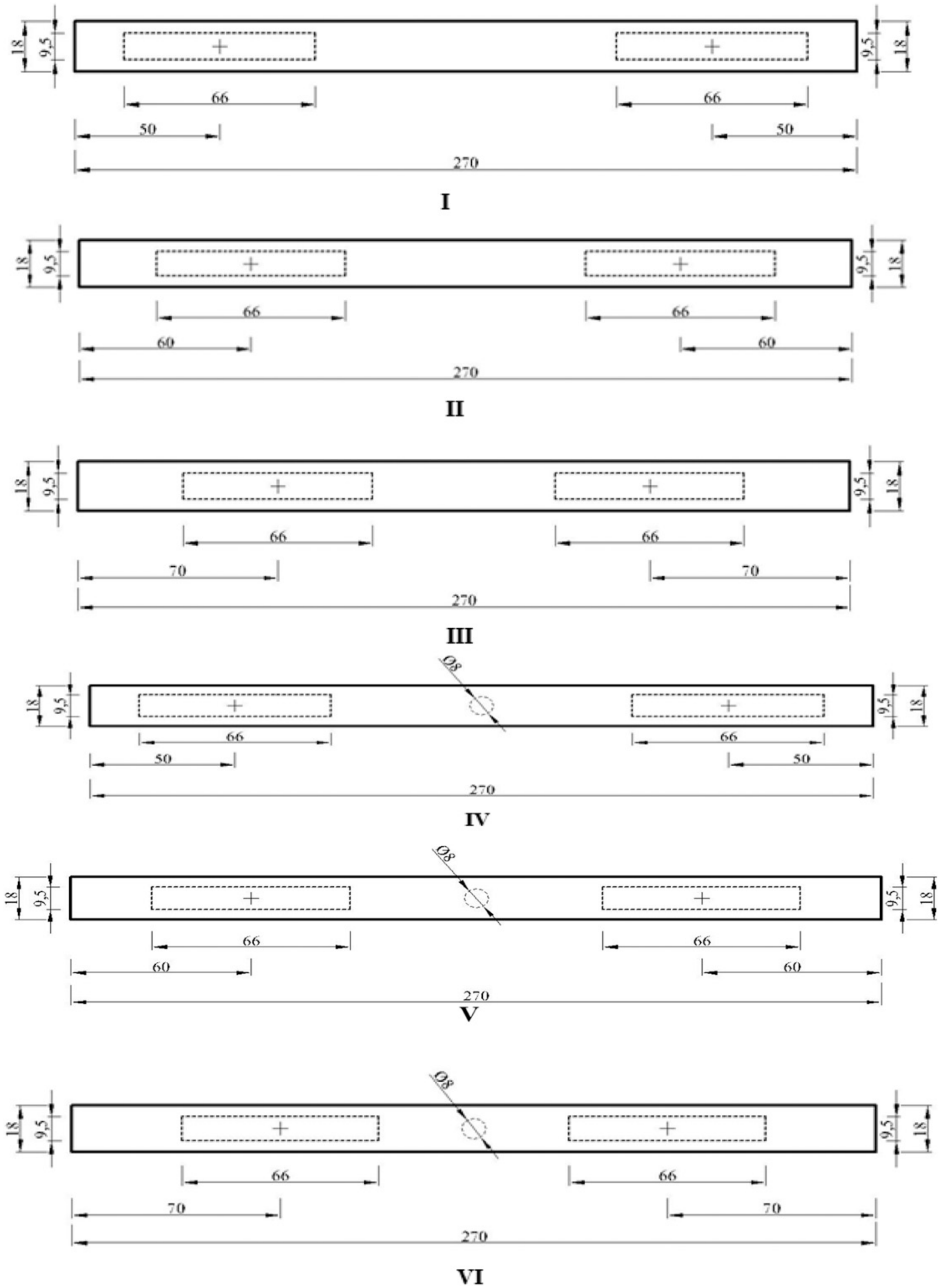

Figure 3. Grooves for catch connector (Clamex P14) and dowel holes on the test samples (dimensions in mm).

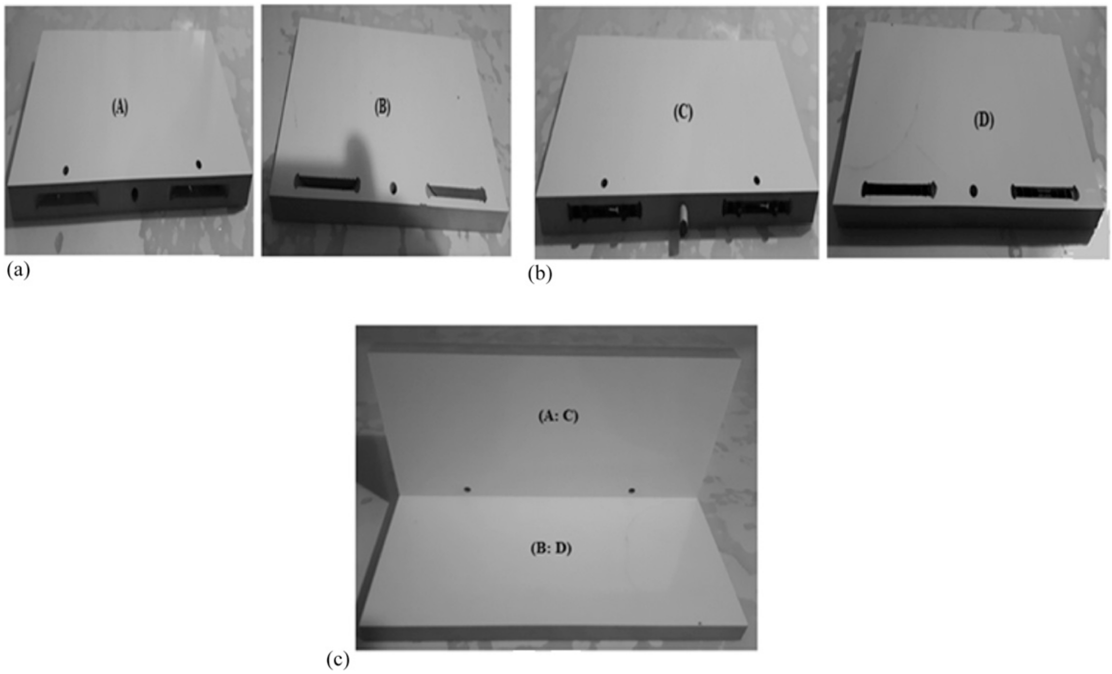

Figure 4. Grooves for the catch connectors, and dowel holes (a), insertion of catch connectors and dowels into the holes (b), and general view of the L-type test sample (c).

in the production of RTA furnitures. Thus, it will contribute to the database of furniture engineering design. It is predicted to be an important resource for researchers who aim to work on this subject.

MATERIALS AND METHODS

The methodology of the present study is as follows:

Materials

All joint specimens were prepared from 18-mm-thick, melamine-coated, medium-density fiberboard (MDF-Lam) which is used extensively in the furniture industry. In this study, dowels with a diameter of 8 mm and a length of 36 mm made from three different wood species which were Orientalis beech (*Fagus orientalis* Lipsky), oak (*Quercus petraea* Lieble), and Scotch pine (*Pinus sylvestris* Lipsky) were used as shown in Fig 1. First, these MDF-Lam panels were tested for MC, density, modulus of rupture (MOR), and modulus elasticity (MOE) according to TS EN323 (1999), TS EN322 (1999), TS EN310 (1999), and ASTM D1037 (2006), respectively, and the wooden materials were tested MC and density, modulus of rupture (MOR), and modulus elasticity (MOE)

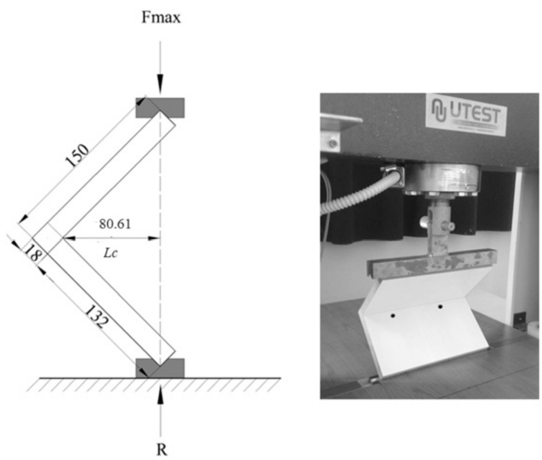

Figure 5. Geometry of joints under compression load (dimensions in mm).

Table 2. Physical and mechanical properties of materials used in test samples.

Materials	MC %	Average-dried density (g/m^3)	Air-dried density (g/m^3)	Modulus elasticity (N/mm^2)	MOR (N/mm^2)
Oak	9.6	0.660	0.670	12,167.08	118.62
Orientalis beech	9.4	0.670	0.680	12,506.25	122.67
Scotch pine	10.2	0.520	0.530	10,203.67	100.08
Melamine-coated medium-density fiberboards	6.8	0.740	0.760	3465	26.02

were tested according to TS 2471 (1976), TS 2472 (1976), TS 2474 (1976), and TS 2478 (1976) standards, respectively. The determined physical and mechanical properties are shown in Table 1.

Preparation of L-Type Corner Joint Specimens

Preparation of dowel specimens. Materials for dowel samples were stored at 20 ± 2°C and 65 ± 3% RH until their weight became stable. Then, 1000 × 11 × 11 mm pieces were cut from panels of Orientalis beech (*Fagus orientalis* Lipsky), oak (*Quercus petraea* Lieble), and Scotch pine (*Pinus sylvestris* Lipsky), and 8-mm-diameter and 36-mm-long dowels were made using a dowel machine.

The general configuration of the L-type corner joint specimens used for this study is shown in Fig 2 (Zhang and Eckelman 1993a, 1993b; Kasal et al 2008).

The specimen consists of two structural members, namely, a face member and an edge member.

The face member was 270-mm long × 150-mm wide × 18-mm thick, whereas the edge member was 270-mm long × 132-mm wide × 18-mm thick. Specimens with different end distances (50, 60, and 70 mm) of catch connectors (Clamex P14), shown in Fig 3, were tested to achieve the most effective position. 66-mm wide × 9.5-mm thick × 13.5-mm depth catch connector (Clamex P14) grooves were drilled into the face of the edge members for catch connector (Clamex P14) housing. According to the plans of this study, one dowel hole of 8-mm diameter and 24 ± 1 mm depth was drilled into 9 mm inside of the edge of the face member with a 135-mm distance from each side. On the joining surfaces in the face

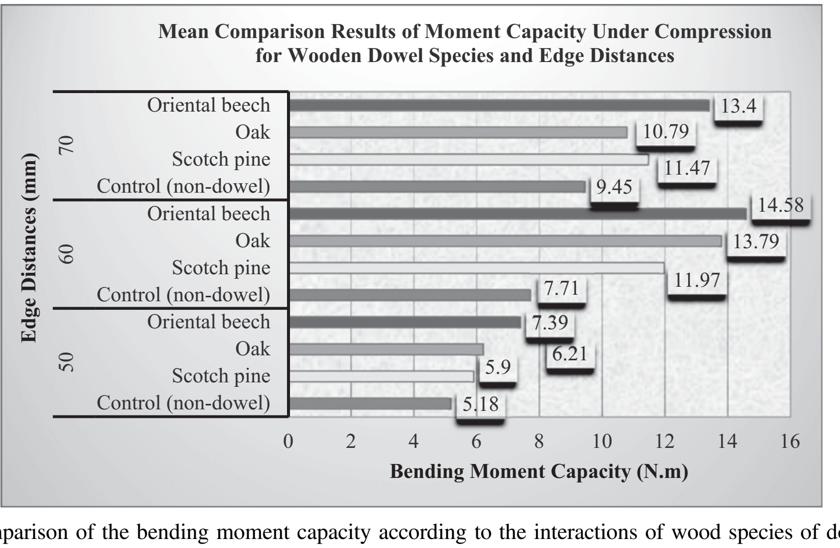

Figure 6. Comparison of the bending moment capacity according to the interactions of wood species of dowels and end distances.

Table 3. Descriptive statistical values of bending moment capacity under compression load.

End distances (mm)	Wood species of dowel	Bending moment capacity (N.m)				
		Xmin	Xm	Xmax	Std.	V%
50	Control (nondowel)	4.26	5.18	7.20	1.228	1.508
	Scotch pine	5.36	5.90	6.71	0.322	0.322
	Oak	5.41	6.21	7.89	1.011	1.023
	Orientalis beech	6.58	7.39	9.32	1.139	1.298
60	Control (nondowel)	5.82	7.71	9.97	1.681	2.826
	Scotch pine	11.26	11.97	12.69	0.639	0.408
	Oak	12.71	13.79	17.08	1.854	3.437
	Orientalis beech	12.77	14.58	16.21	1.226	1.504
70	Control (nondowel)	8.01	9.45	11.62	1.321	1.744
	Scotch pine	9.11	11.47	13.62	1.698	2.884
	Oak	8.39	10.79	12.27	1.802	3.249
	Orientalis beech	11.41	13.40	14.93	1.432	2.050

Xm: mean; Xmax, maximum; Xmin, minimum; Std., standard deviations; V%, coefficient of variation.

members, one hole of 8-mm diameter and 12 ± 1 mm depth was drilled into the center of the joining surface with a 135-mm distance from each side. Then, according to the determined configurations, the face and edge members were assembled together, and 120 test specimens were prepared for each end distances and wood species of dowels. The distance between the centerlines of the catch connector (Clamex P14) and dowels were 32, 42, and 52 mm. Joining intersection surfaces and a general view of L-type corner joint test samples are given in Fig 4.

As shown in Fig 4, the configuration of the test samples was prepared as three edge distances × (three different wood species of dowels + 1 w/out dowel) × 10 replications (3 × 4 × 10 = 120) are given in Table 1. Specimens with an end distance of 50 mm without the wooden dowel.

1. Specimens with an end distance of 60 mm without the wooden dowel.
2. Specimens with an end distance of 70 mm without the wooden dowel.
3. Specimens with an end distance of 50 mm with the wooden dowel.
4. Specimens with an end distance of 60 mm with the wooden dowel.
5. Specimens with an end distance of 70 mm with the wooden dowel.

The assembled specimens were stored at 20 ± 2°C and a RH of 65 ± 3% till the test time. Ten replicate samples for three different wood species of dowels (Orientalis beech, oak, and Scotch pine, and nondowel, respectively) and three different end distances (50, 60, and 70 mm) were tested.

Method of testing. The tests were carried out on a universal test system (UTEST), universal testing machine, with a 10-kN capacity, in the mechanical test laboratory of wood and wood composites in Kutahya Dumlupınar University,

Table 4. Summary of the analysis of variance results for compression tests.

Source	DF	Adj SS	Adj MS	F-value	*p*-value
Wood species of dowel (A)	2	404.71	202.353	26.168	0.000[a]
End distances (B)	3	404.90	48.601	109.168	0.000[a]
A × B	6	48.60	8.146	4.40	0.001[a]
Error	48	89.02	1.854	—	—
Pure error	59	688.596	—	—	—
Total	60	6474.54	—	—	—

[a] p-value < 0.05 is a significant difference.

Simav Faculty of Technology (Turkey). All joints were loaded as shown in Fig 5. The loading rate was 6 mm/min. Maximum loads read from the test machine were recorded in units of Newton. Compression loads were used to calculate the bending moment capacity. The relationship between the bending moment resistance and applied maximum failure loads under compression was used to determine F_{max}. The bending moments were calculated from Eq 1.

$$M_c = F_{max} \times L_c, \tag{1}$$

where M_c is the bending moment in diagonal compression (N.m), F_{max} is the ultimate force at time of failure (N), and L_c is the horizontal distance from force applied to the rotation point (m). The moment arm (L_c) was calculated as 0.08061 m for compression loads.

Statistical analyses. The data were analyzed by using the Minitab® 18 software (Minitab, Ltd., Coventry, UK). Analysis of variance (ANOVA) was performed to quantify the differences between variables. The analyses variance analysis was carried out on the data at the 0.05 significance level for the individual data to examine the main factors (the wood species of dowels and the end distance) and their interactions on the bending moment resistance of the joints. Tukey' test was carried out to determine the importance of the differences between the groups.

RESULTS AND DISCUSSION

The average values for moisture-dried density, air-dried density, MC, MOE, and the MOR of the materials are given in Table 2.

The mean, minimum, maximum, and standard deviation values of the bending moment resistance of the joints under diagonal compression load are given in Table 2 and Fig 6.

As shown in Table 3, when the end distance of the catch connector (Clamex P14) groove from its center was 50 mm, the bending moment resistance of the experimental samples with Orientalis beech dowel was 19% higher than that of the oak dowel, 25% higher than that of the Scotch pine dowel, and 43% higher than that of the control samples.

Table 5. Mean comparison results of moment capacity under compression for wood species of dowel.

Wood species of dowel	Mean bending moment (N.m)	HG
Orientalis beech	11.79	A
Oak	10.27	B
Scotch pine	9.78	B
Control (nondowel)	7.44	C

HG, homogeneous groups.

When the end distance of the catch connector (Clamex P14) groove from its center was 60 mm, the bending moment resistance of the experimental samples with Orientalis beech dowel was 6% higher than that of the oak dowel, 22% higher than that of the Scotch pine dowel, and 89% higher than that of the control 3the end distance of the catch connector (Clamex P14) was 70 mm, the bending moment resistance of the experimental samples with Orientalis beech dowel was 17% higher than that of the oak dowel, 28% higher than that of the Scotch pine dowel, and 42% higher than that of the control samples.

ANOVA results for the bending moment resistance values of the tested joints are given in Table 4.

The effects of different wood species of dowels and the end distance of catch connector (Clamex P14) on the bending moment resistance of joints were significant at $p < 0.05$. Furthermore, the two-factor interaction was not statistically significant at $p < 0.05$.

To determine the difference between all the variables, Tukey's test was performed, and results reflecting the interaction between wood species of dowels and end distances are shown in Tables 5 and 6, Figs 7 and 8.

Table 6. Comparison results of the bending moment capacity for the end distance.

End distances (mm)	Mean bending moment (N.m)	HG
60	12.01	A
70	11.28	A
50	6.17	B

HG, homogeneous groups.

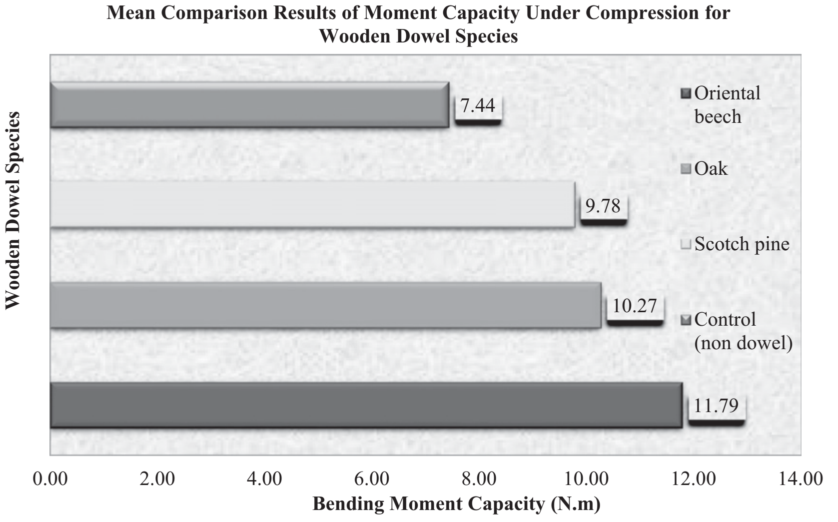

Figure 7. Comparison of the bending moment capacity of different wood species of dowels.

As shown in Table 4, there was a statistically significant difference between the bending moment resistance of the wood species of dowels. When the comparison results of wood species of dowels were examined, it was seen that the highest moment resistance was obtained from Orientalis beech. The moment resistance of oak and Scotch pine specimens was much lower. In this context, Orientalis beech dowels are approximately 15% stronger than oak dowels, 21% stronger than Scotch pine dowels, and 58% stronger than control samples (nondowel). The physical and mechanical properties of Orientalis beech wood were higher than those of the other woods used in the experiments.

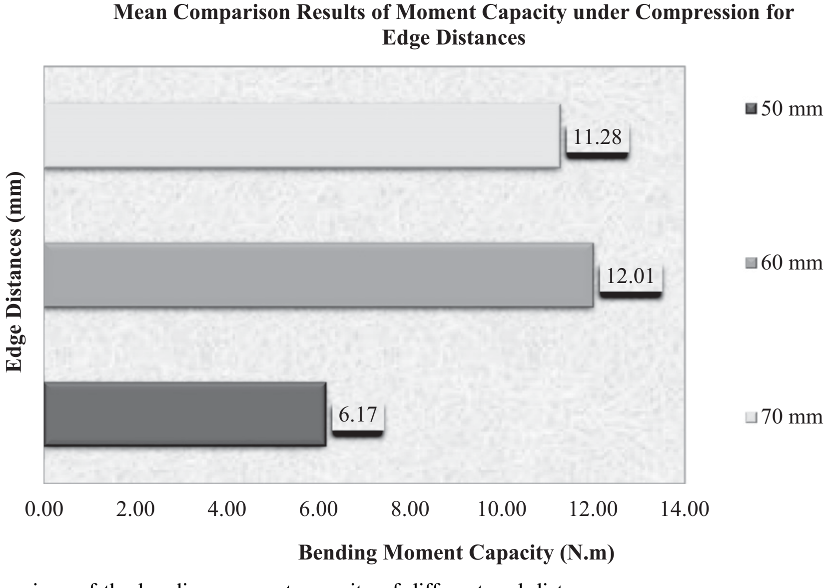

Figure 8. Comparison of the bending moment capacity of different end distances.

Table 7. Model summary[a] of regression analysis.

Model	R	R square	Adjusted R square	Std. error of the estimate
1	0.677[b]	0.458	0.439	2.55926

[a] Dependent variable, bending moment.
[b] Predictors, (constant), the end distance of catch connectors, wood species of dowel.

Karaman and Yıldırım (2019) indicated that the highest moment carrying capacity under diagonal tensile and diagonal compression load was of ash dowel, Orientalis beech dowel, and chestnut dowel, respectively. Dalvand et al (2014) discovered that joints with beech dowels had higher resistance than those with hornbeam dowels.

The mean comparisons of the bending moment capacity of L-type joints for end distances are given in Table 5, and the corresponding diagram is shown in Fig 8. The bending moment capacity reached its maximum level in samples with a 60-mm end distance. When the end distance was increased from 50 mm to 60 mm, bending moment resistance increased dramatically. On the other hand, as the end distance was increased from 60 mm to 70 mm, bending moment resistance decreased more slowly.

Zhang and Eckelman (1993b) claimed that the dowel spacing must be at least 76 mm, whereas Tankut (2005) stated that the distance must be at least 96 mm. Lui and Eckelman (1998) estimated that both for glued dowels and screws, the bending moment capacity of the joints decreased as the spacing between the fasteners was decreased below 60 mm. Simek et al (2010) found out that the cam joints with an end distance of 60 mm had significantly higher moment capacity than the joints with an end distance of 30 and 90 mm. Norvydas et al (2005) indicated that the joint resistance was at its highest when the distance between the dowel and the edge was 55 mm. Malkocoglu et al (2013) determined that the moment resistance increased for both MCP and MCF when the dowel spacing was increased up to 160 mm. However, the moment resistance decreased as the dowel spacing was increased from 160 to 192. Malkocoglu et al (2014) found out that strength increased as the end distance decreased. They determined that end distances of 50 and 60 mm had higher resistance than 70 and 80 mm. Karaman et al (2020) studied the effects of edge distances of fastener types on the bending moment of L-type corner joints for RTA furnitures. They determined that the Clamex P14 connector performed best with an edge distance of 90 mm.

Regression Analysis

Multiple variance regression analysis was performed for predicting the bending moment variable from variables of wood species of dowels, and end distance of catch connectors are shown in Tables 7-9. According to the results of the analysis, a significant regression model, $F\,(2, 114) = 24.07$, $p < 0.05$, explained the 44% of the variance in the dependent variable ($R^2_{\text{adjusted}} = 0.44$) by independent variables. Accordingly, it can be predicted that the effect of wood species of dowel on the bending moment is positive and significant, $\beta = 0.28$, $t\,(114) = 2.89$, $p < 0.05$, $pr^2 = 0.13$. Similarly, the effect of end distance of the catch connector on the bending moment is predicted to be positive and significant, $\beta = 0.62$, $t\,(114) = 6.31$, $p < 0.05$, $pr^2 = 0.41$. Regression lines for L- type joint at compression tests are given Fig 9.

Table 8. Regression analysis summary of the analysis of variance[a] results for compression tests.

Model		Sum of squares	df	Mean square	F	Sig.
1	Regression	315.258	2	157.629	24.066	0.000[b]
	Residual	373.338	114	6.550	—	—
	Total	688.596	118	—	—	—

[a] Dependent variable, bending moment.
[b] Predictors, (constant), the end distance of catch connectors, wood species of dowel.

Table 9. Linear regression coefficient[a] results for compression tests.

Model		UStd. coef.		Std. coef.			95.0% Confidence interval for B		Correlations			Collinearity statistics	
		Beta	Std. error	Beta	t	Sig.	Lower bound	Upper bound	Zero-order	Partial	Part	Tolerance	VIF
1	C	2.581	1.145		2.255	0.028	0.289	4.872	—	—	—	—	—
	X_1	0.854	0.296	0.282	2.890	0.005	0.262	1.446	0.282	0.357	0.282	1.000	1.000
	X_2	2.552	0.405	0.615	6.307	0.000	1.742	3.363	0.615	0.641	0.615	1.000	1.000

C, constant; UStd. coef., unstandardized coefficents, Std. coef., standardized coefficents. X_1, wood species of dowel; X_2, the end distance of catch connectors.
[a] Dependent variable, bending moment.

The bending moment regression equations are found as shown in Eq 2.

$$\hat{Y} = 2.581 + 0.584 \times X_1 + 2.552 \times X_2. \quad (2)$$

Bending moment = 2.581 + 0.854 × wood species of dowel + 2.552 × the end distance of catch connectors.

Types of Deformation

Deformations observed during the bending moment capacity tests of L-type corner joints with a catch connector (Clamex P14) and Orientalis beech (*Fagus Orientalisis* L.), oak (*Quercus petraea* L.), and Scotch pine (*Pinus sylvestris* L.) dowels are shown in Fig 10.

Although no deformation was observed in the connecting element, dowels used for support were bent. The MDF-Lam was fractured due to the compression force on the connector. It can be said that the deformations happened almost in the same way in all experimental specimens. In addition, it has been determined that the deformations on the edges of the vertical parts where the fasteners are located occurred in the

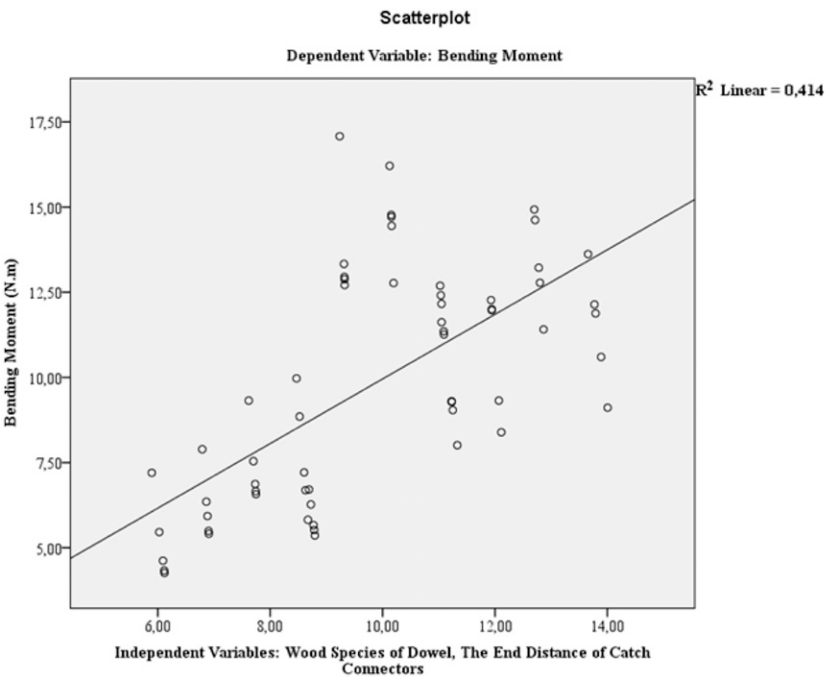

Figure 9. Regression line for L-type joint at compression tests.

Figure 10. Types of deformation of L-type corner joints resulting from the compression test; 50 mm end distance + control (nondowel) (a), 50 mm end distance + oak dowel (b), 50 mm end distance + oriental beech dowel (c), 50 mm end distance + scotch pine dowel (d), 60 mm end distance + control (nondowel) (e), 60 mm end distance + oak dowel (f), 60 mm end distance + oriental beech dowel (g), 60 mm end distance + scotch pine dowel (h), 70 mm end distance + control (nondowel) (ı), 70 mm end distance + oak dowel (i), 70 mm end distance + oriental beech dowel (j), and 70 mm end distance + scotch pine dowel (k).

form of slits. Our results showed, however, that the optimum wood species for dowels was Orientalis beech and the optimum end distance for catch connectors was 60 mm. Both a decrease in the end distance from 60 to 50 mm and an increase from 60 to 70 mm reduced the joint strength. Therefore, thanks to these studies, researchers can provide a range of optimum values for parameters affecting the furniture joint strength, and this could be helpful for engineering design of furniture structures.

CONCLUSIONS

This study presents the bending moment resistance of wood species of dowels used in L-type corner joints with catch connector (Clamex P14), under compression load. The effect of the end distance (50, 60, and 70 mm) was also considered. In general, the bending moment capacity of L-type corner joints under compression loads was significantly affected by the wooden dowel species, the end distances, and the interaction of these two factors.

In particular, the tests showed the following:

1. Catch connector (Clamex P14) with an end distance of 60 mm had the highest moment capacity between the three end distances tested. This was followed by 70 mm and 50 mm, respectively.
2. For the wood species of dowels, Orientalis beech showed the highest performance, and this was followed by oak, Scotch pine, and nondowel, respectively. This can be explained by the density of Orientalis beech being higher than those of other wood species tested in this study.
3. The comparison results of end distances regarding the bending moment capacity, as well as the results of the experiments conducted in this study, indicate that the use of connectors with an end distance of 60 mm along with beech dowels appears to be the most ideal. The use of connectors with an end distance of 50 mm without dowels (control samples) appears to be the least ideal.
4. The bending moment capacities of L-type corner joints connected with beech dowels were higher than those connected with oak or Scotch pine dowels.

The results of this study provide fundamental information on the strength properties of the selected catch connector (Clamex P14) as an RTA fastener, which will be useful for the RTA furniture manufacturers and the engineering design of furniture constructions. It would be advisable to test different materials and combinations within this context.

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