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The diagonal tensile strength of corner joints constructed with different connectors

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Abstract: This study aimed to investigate the strength and stiffness of corner joints for case furniture in the diagonal tension test. For this purpose, joint members were constructed with medium-density fiberboard (MDF) and particleboard (PB) with minifix, butterfly, and trapeze connectors. The study also observed the role of the end distance of the connectors, which was found to be a factor in joint strength and stiffness. According to the results, joints made of MDF performed 16 to 92 % better compared to PB, considering connectors on joints, which was evident due to material properties that MDF were denser by 7.5% and more strengthfull by 177% than PB. The butterfly connectors had the highest strength and stiffness regardless of material type and end distance, followed by trapeze connectors. The joints with minifix connectors had strength and stiffness of 2-3 times lower than others. Moreover, the end distance of 75 mm provided slightly higher joint strength and stiffness compared to those of 50 mm but was not statistically significant. Consequently, butterfly connectors demonstrated markedly the highest strength and stiffness for corner joints of case furniture. Furniture made of MDF should be chosen for higher durability rather than PB.
Keywords. Diagonal tension test, Corner joints, Knockdown connectors, End distance

Farklı bağlantı elemanları ile üretilmiş köşe birleştirmelerinin diyagonal çekme dayanımı

Öz: Bu çalışmanın amacı kutu tipi mobilyaların köşe birleştirmelerinin diyagonal çekme testi altında dayanımını ve rijitliğini incelemektir. Bu doğrultuda, birleştirme, lif levha (MDF) ve yonga levha (YL) panelleri kullanılarak minifix, kelebek ve trapez bağlantı elemanlarıyla oluşturulmuştur. Ayrıca, bağlantı elemanlarının köşe birleştirme kenar mesafesi de gözlemlenmiştir. Çalışma sonuçlarına göre, MDF, YL'dan %7.5 daha yoğun ve %177 daha dayanıklı olmasından dolayı, bu malzeme ile yapılan birleştirmeler YL panelinden yapılan birleştirmelere göre kullanılan bağlantı elemanı dikkate alındığında %16 ila %92 arasında daha iyi performans göstermiştir. Kelebek bağlantı elemanları, malzeme türü ve köşe birleştirme kenar mesafesinden bağımsız olarak en yüksek dayanım ve rijitliğe sahiptir, trapez bağlantı elemanları onları takip etmektedir. Minifix bağlantı elemanlarıyla yapılan birleştirmeler diğerlerine göre 2-3 kat daha düşük dayanım ve rijitliğe sahiptir. Ayrıca, 75 mm köşe birleştirme kenar mesafesi, 50 mm olanlara göre biraz daha yüksek bir birleştirme dayanımı sağlamıştır ama istatistiksel olarak anlamlı değildir. Sonuç olarak, kutu tipi mobilyaların köşe birleştirmelerinde kelebek bağlantı elemanları belirgin bir şekilde en yüksek dayanımı ve rijitliğini göstermiştir. Mobilya yapımında MDF malzemesinin tercih edilmesi, YL malzemesine göre daha yüksek dayanıklılık sağlamaktadır.
Anahtar kelimeler: Diyagonal çekme testi, Köşe birleştirme, Demonte bağlantılar, Kenar mesafesi

1. Introduction

Case-type furniture constructions are widely used in the furniture industry, utilizing solid wood or wood-based composite panels with joinery systems with a self-locking system and demountable features. The strength and durability of case furniture are critical factors that influence its longevity and functionality. The type of joinery used plays a pivotal role among the various elements that contribute to these properties. Furniture design has increasingly incorporated innovative connectors such as minifix, butterfly, and trapeze connectors, each offering unique advantages in terms of ease of assembly, cost, and mechanical performance.

Research endeavors regarding the strength of the corner joints for the case furniture remain highly pertinent and worthy of continued exploration. Recently, the joint strength of case furniture has been studied by considering material type, joint type, adhesive types, dimension of the materials and connectors, joinery techniques, and newly developed connectors.

Yuksel et al. (2015) stated that joint strength with confirmat and screws was higher than joints with minifix; namely, it could be said that minifix connectors provided sufficient strength for joints but performed less compared to screwed joints. Demirci et al. (2020) evaluated the effect of the wood species, number of teeth, and adhesive type on wood corner joints and concluded that the density of the

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materials highly influenced joint strength, and an increase in the number of teeth enhanced joint strength. Smietanska and Mielczarek (2022) indicated that corner joints made of MDF have higher strength compared to PB, approximately 34-47%, depending on joint types. Similarly, Yuksel et al. (2015) observed a 36-69% ratio. Denser wood-based composite materials have higher joint strength, correspondingly higher bending properties, internal bond strength, and screw-holding capacity. Minifix joints are mainly used with dowels to resist moment on the corner joint. Yerlikaya and Aktas (2012) reinforced the minifix+dowel joint with glass-fiber composite layers and enhanced joint strength by 158% and 20% in the diagonal compression and tension tests, respectively. Besides, an increase in dowel diameter and penetration depth in corner joints increased the joint strength. Dalvand et al. (2014) expressed that joint strength enhanced with an increase in dowel penetration depth from 9 to 13 mm and 13 to 17 mm, and dowel diameter from 6 to 8 mm but reducing 8 to 10 mm. Due to the thickness of wood-based composite materials, an increase in dowel diameter severely decreases joint strength. The thickness of the remaining dowel holes was reduced, causing stress on the corners and causing the earlier failure. Klos and Langova (2023) presented the calculation of the reliability of case furniture made of MDF and PB with minifix, dowel, and confirmat screws by observing the strength of the corner joints.

Hajdarevic and Martinovic (2015) highlighted that end distances significantly affected joint strength by changing stress patterns in fracture zones. In the case of an end distance of 52 mm, the joint had a maximum joint stiffness comparable to those of 20 and 84 mm. By decreasing end distances to 20 mm, joint stiffness decreased by 8.5%, while those of 82 mm were 12%. Karaman (2021) investigated the effects of end-distances of Clamex P14 on joint strength and indicated that an increase in end distance from 50 to 60 mm increased the joint strength, but those of 60 to 70 mm decreased. Yet, there were increases in joint strength while increasing the end distance from 50 to 70 mm. Otherwise, Malkacoglu et al. (2013) observed that joint strength decreased when the end distances increased from 50 to 80 mm. Simek et al. (2008) examined the effects of end distance on corner joints of diagonal compression strength and highlighted that an increase in end distances from 30 to 60 mm enhanced joint strength while those of 30 to 90 mm decreased, but this reduction was not statistically different. The studies showed that end distances influenced the joint strength somewhat; namely, its increase was insignificant or did not contribute to joint strength after a certain distance point.

Recently, innovative and additively manufactured connectors have been studied and compared to commonly used connectors for joints of case furniture. Krzyzaniak and Smardzewski (2019) developed new, innovative two-plastic connectors and benchmarked them with a minifix connector. The results showed that newly developed joints had strength as much as joints with minifix. Kasal et al. (2023) evaluated the strength of corner joints with newly designed auxetic dowels, benchmarking them against plain dowels in the diagonal tensile and compression test. The result showed that auxetic dowels did not provide higher strength but were assembled easily without any tools. Kuskun et al. (2023) optimized the auxetic dowels using Monte Carlo Simulation and provided a new solution that these dowels were suitable for corner joints.

Adhesive types used in corner joints significantly affect joint strength. Karaman (2020) stated that PVA adhesive had 9-12 % and 14-18% higher strength compared to PU adhesive in the diagonal tensile and compression tests, respectively. Similarly, Demirci et al. (2020) indicated that PVA performed better than PU.

Lightweight case furniture has become prominent due to its life cycle and consideration of design for the environment. Petrova et al. (2023) stated that thin and ultra-thin wood-based composite materials could be suitable for corner joints. It was suggested that 10 mm MDF and 12 mm PB could provide efficient strength for corner joints with a miter joinery system by increasing the surface area of the joined edges.

This paper investigates the strength and stiffness of joints for case furniture in the diagonal tension test, one of the key indicators of its resistance to racking forces and overall structural integrity. This study aims to evaluate and compare the moment capacity and stiffness of joints for case furniture assembled using minifix, butterfly, and trapeze connectors. This evaluation will provide insights into the effectiveness of these joinery methods in enhancing the structural integrity and durability of furniture. For this purpose, the objectives of the study were (i) to conduct a series of moment capacity and stiffness in diagonal tension tests for case furniture assembled using minifix, butterfly, and trapeze connectors, (ii) to analyze the data collected from these tests to determine the comparative strengths and weaknesses of each joinery method (iii) to identify which connector type offers the best performance in terms of moment capacity and stiffness and (iv) to provide recommendations for furniture designers and manufacturers on the optimal use of these connectors for improved furniture durability and functionality.

Understanding the relationship between joinery types and strength and stiffness can lead to more rational decisions in furniture construction, ensuring both aesthetic appeal and robust functionality. This study highlights the practical implications of minifix, butterfly, and trapeze connectors in contemporary furniture design. The results of the study will contribute to the field of furniture design and manufacturing by (i) enhancing knowledge about the mechanical performance of different joinery methods, (ii) providing practical insights for designers and engineers to optimize the structural performance of case furniture and (iii) supporting the development of more durable and reliable furniture products through informed material and design choices.

2. Material and method

2.1. Materials

This study used particle board (PB) and medium density fiber (MDF) with a thickness of 18 mm to determine the strength and stiffness of the corner joints. Three distinct connectors were used to join members, namely, minifix (D:15 mm, H:13 mm, and L:50 mm, Figure 1.a), butterfly (Figure 1.b), and trapeze (Figure 1.c). 8x30 mm plastic dowels for minifix connectors (Figure 1.a), 3.5x18 mm screws for the butterfly, and 3.5x25 mm screws for the trapeze were used to construct the joint, and the penetration depth for a screw for each connector was approximately 16 mm.

(a) (b) (c)

Figure 1. Connectors used in the study: a. Minifix+dowel, b. Butterfly, and c. Trapeze

2.2. Determination of density and moisture content

According to TS EN 323 (1999), five test specimens for each sample group with 18 x 50 x 50 mm dimensions were prepared. All specimens were acclimatized at 20 ± 2 ° C and 65 ± 5% relative humidity according to TS-EN 326-1 (1999), and weighed with a 0.01 g precision scale. Their dimensions were measured with a 0.01 precision caliper. The density of the PB and MDF panels was calculated using Equation 1.

$$\rho = \frac{m}{V} \quad (1)$$

Where, ρ is the density (gr/cm^3), m is the weight of the material (gr), and V is the volume of the material (cm^3).

2.2. Determination of Modulus of Rupture and Modulus of Elasticity

According to TS EN 310 (1999) all specimens for each material were prepared with dimensions of 18 x 50 x 410 mm and five replications for three-point bending tests (Figure 2). All tests were conducted on a SHIMADZU test machine until non recoverable failure occurred with a rate of 10 mm/min. In the three-point bending tests, load-deformation curves were obtained for PB and MDF specimens. These curves were used to calculate the modulus of rupture (*MOR*, MPa) and modulus of elasticity (*MOE*, MPa) of the materials according to Equations 2 and 3, respectively.

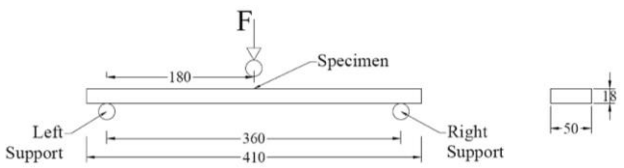

Figure 2. Test configuration for three-point bending test (in mm)

$$MOR = \frac{3 \times F_{max} \times L}{2 \times b \times h^2} \quad (2)$$

Where, F_{max} is the maximum load capacity (N), L is the span length (mm), b is the specimen breath (mm) and h is the specimen thickness (mm).

$$MOE = \frac{\Delta F \times L^3}{4x\Delta d \times b \times h^2} \quad (3)$$

Where, ΔF is the difference between two loads in the elastic region of the load-deformation curve (N) and Δd is the deformations corresponding to loads for ΔF (mm).

2.3. Specimen constructions and diagonal tension test of joints

All parts are cut from PB and MDF with dimensions of 18x182x300 mm and 18x200x300 mm for members joined vertically and horizontally, respectively, as shown in Figure 3. Three joinery types were selected, primarily used in the furniture industry: namely, minifix+dowel, butterfly, and trapeze. Joints were positioned at distances of 50 mm and 75 mm from ends (end-distances). Five replications were prepared for each sample group; correspondingly, 60 samples were prepared with an experiment design for 5 replications x 2 material types x 3 joint types x 2 end distances.

All tests were conducted on the SHIMADZU universal test machine at a rate of 10 mm/min until the maximum load was reached or a non-recoverable failure occurred. The test configuration is given in Figure 4. In diagonal tension tests, maximum loads were used to calculate the moment capacities of the joints using Equation 4.

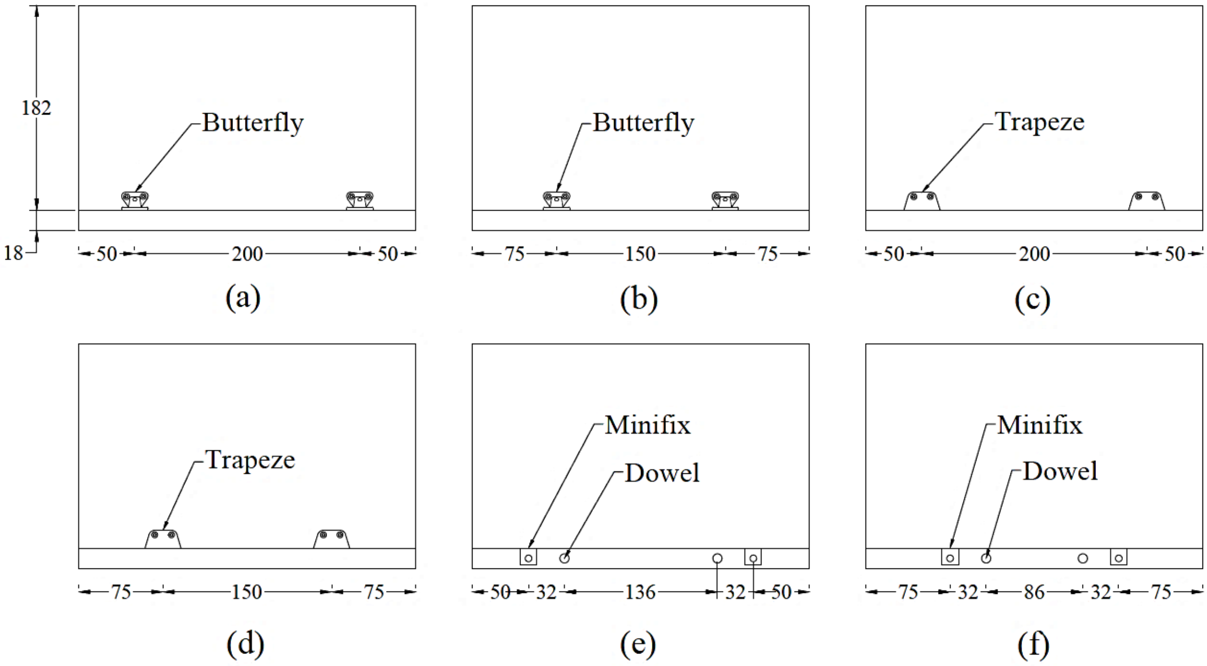

Figure 3. Joint configurations: a. Butterfly connector at the end distance of 50 mm, b. Butterfly connector at the end distance of 75 mm, d. Trapeze connector at the end distance of 50 mm, d. Trapeze connector at the end distance of 75 mm, e. Minifix +dowel at the end distance of 50 mm and f. Minifix +dowel at the end distance of 75 mm

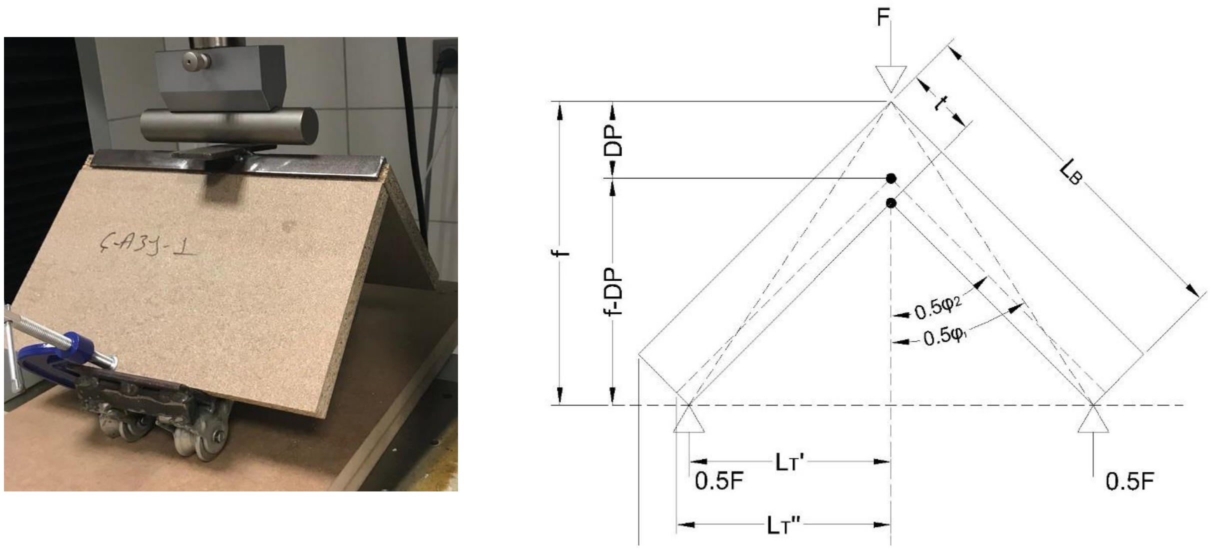

Figure 4. Diagonal tension test configuration

$$M_T = 0.5F_{max} \times L_T' \tag{4}$$

Where, M_T is the moment capacity of the joint in the diagonal tensile test (Nm), F_{max} is the maximum load in the diagonal tensile test (N), and L_T' is the moment arm (m, 0.12728 m).

Equations 5 to 11 were used to calculate the stiffness (K_T, Nm/rad) of the connector in the tension test by considering the angle (φ, rad) after deflection. The dimensional and rotational parameters are given in Figure 4 (Kasal et al., 2023).

$$K_T = \frac{M_T}{\varphi} \tag{5}$$

$$\varphi = \varphi_2 - \varphi_1 \tag{6}$$

$$L_T' = (L_B - t) \times \cos 45 \tag{7}$$

$$0.5\varphi_1 = \tan^{-1}\left(\frac{L_T'}{f}\right) \tag{8}$$

$$0.5\varphi_2 = \tan^{-1}\left(\frac{L_T''}{f-DP}\right) \tag{9}$$

$$f = L_T' + (\sin 45 \times t) \tag{10}$$

$$L_T'' = \sqrt{(L_T')^2 + f^2 - (f-DP)^2} \tag{11}$$

Where, DP is deflection point, f is height of the corner joint in test configuration (mm), L_B is length of the butt member, t is thickness of the member and L_T'' is moment arm after deflection.

2.4. Statistical analysis

Data was collected for the presence of statistical significance among all sample groups through MANOVA for three experimental parameters of joints, and Tukey pair-wise comparisons for joint sample groups were examined in SPSS 22.

3. Results and discussion

3.1. Some physical and mechanical properties of the materials used in joints

Table 1 gives results for density, moisture content, MOR and MOE of the PB and MDF. The densities of PB and MDF were 0.66 gr/cm^3 and 0.71 gr/cm^3, respectively, and the moisture contents were 6.25% and 5.57%, respectively. The MOR for the PB was 13.10 MPa with a standard deviation of 0.90 MPa, and those of the MDF were 36.89 MPa and 1.22 MPa, respectively. Besides, the MOEs for the PB and MDF were 2520.32 MPa with a standard deviation of 106.16 MPa and 3419.00 with a standard deviation of 55.46 MPa.

Figure 5 gives maximum load and deformation at the maximum load of the joints. According to the results, joints made of PB with *minifix* showed the lowest load levels (approximately 200 N) and average deformations (9 to 18 mm). Those of MDF had a maximum load of around 400 N and the deformation between 8 and 15 mm. The highest deformation range was 12 to 21 mm for joints made of PB with a *trapeze connector*. The highest maximum loads and the lowest deformations were observed for the joints made of MDF with *butterfly connectors*.

3.2. Strength and stiffness of corner joints

Figure 6 gives the failure mode of the *butterfly* and *trapeze* connectors. The surface of PB failed due to stresses occurs close to *butterfly* connectors (Figure 6a) or *butterfly* connectors were failed (Figure 6b). In *trapeze* connectors, screws were pulled out from members (Figure 6c) or plastic parts of *trapeze* were failed (Figure 6d). The observed particular failures for the joint with *minifix* were that plugs were stuck out from their hole.

Table 1. Density and moisture content of the materials

Material		Density (gr/cm^3)	Moisture content (%)	Modulus of rupture (MPa)	Modulus of elasticity (MPa)
	Mean	0.66	6.25	13.10	2520.32
PB	Std Dev*	0.01	0.82	0.91	106.16
	CoV*	1.76%	13.06%	6.94%	4.21%
	Mean	0.71	5.57	36.89	3419.00
MDF	Std Dev*	0.00	0.35	1.22	55.46
	CoV*	0.49%	6.22%	3.31%	1.62%

** Std Dev: Standard deviation and CoV: Coefficient of variation*

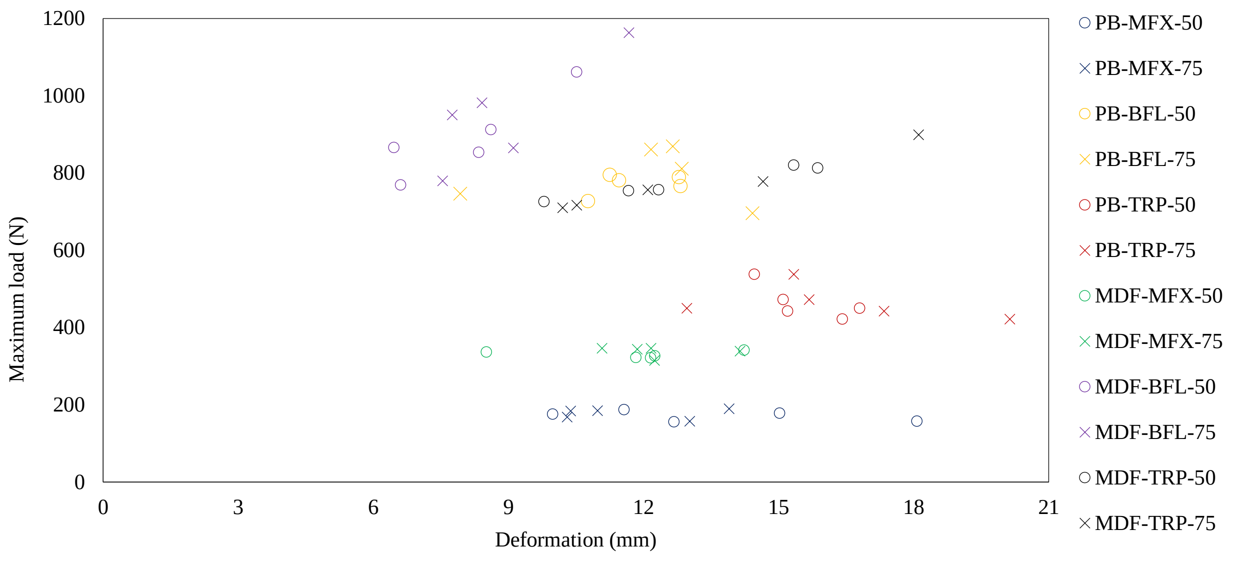

Figure 5. Maximum loads and deformations at the maximum loads for joints in diagonal tension test.

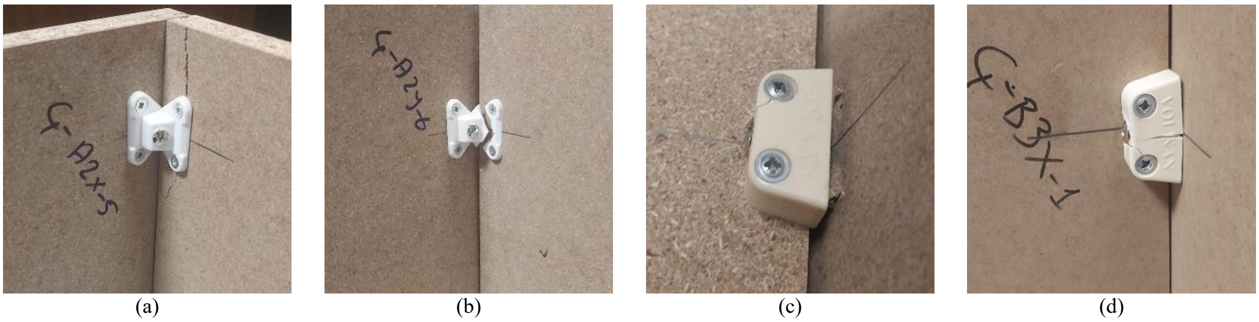

Figure 6. Failure mode for a. and b. butterfly, and c. and d. trapeze connectors.

Figure 7 illustrates the average moment capacity of the corner joints constructed from PB and MDF using three distinct fastening methods: minifix, butterfly, and trapeze. The moment capacities are measured at two different fastener end distances: 50 mm and 75 mm. Joints with *minifix fastener* at an end-distance of 50 mm were 10.88 Nm for PB and 20.99 Nm for MDF, with standard deviations of 0.87 Nm and 0.55 Nm, respectively. Those of 75 mm were 11.26 Nm for PB and 21.54 Nm for MDF, with standard deviations of 0.86 Nm and 0.85 Nm, respectively. The moment capacity of MDF significantly surpasses approximately 92% of that of PB at both 50 mm and 75 mm end distances. Joints with *butterfly connectors* at an end-distance of 50 mm were 49.20 Nm for PB and 56.87 Nm for MDF with standard deviations of 1.74 Nm and 6.87 Nm, respectively. Those of 75 mm were 50.78 Nm for PB and 60.41 Nm for MDF, with standard deviations of 4.75 Nm and 9.17 Nm, respectively. Joints with *butterfly connectors* demonstrated markedly higher tensile strengths compared to those of *minifix* and *trapeze* for both PB and MDF, with MDF again exhibiting approximately 16-19% superior performance over PB. Joints with *trapeze connectors* at an end-distance of 50 mm were 29.61 Nm for PB and 49.06 Nm for MDF with standard deviations of 2.84 Nm and 2.80 Nm, respectively. Those of 75 mm were 32.59 Nm for PB and 49.59 Nm for MDF, with standard deviations of 1.89 Nm and 4.54 Nm, respectively. Joints with *trapeze connectors* also showed higher moment capacities than joints with minifix, with MDF displaying approximately an advantage of 52-65% over PB. In the literature, joints with *trapeze connectors* were 2.5-3 times greater than those of *minifix*. Here, it does not matter which materials or end distances were used; joints made of PB with *trapeze connections* at an end distance of 50 mm were 2.72 and 2.89 times greater than those of *minifix* at an end distance of 50 mm. Similarly, these ratios for those of 75 mm were 2.33 and 2.31 for joints made of MDF, respectively.

An increase in end-distance slightly increased the joint strength for each joint type and material type. The lowest increase for the joint strength with end-distances was 1.08% for the joint with trapeze made of MDF, whereas those made of PB were the highest with an increase of 10.06%.

Table 2 shows the MANOVA results of the moment capacity of the joint with parameters of material types, end-distances, and joint types. According to the results, (i) material types (p-value=0.00), (ii) joint types (p-value=0.00), and (iii) the interaction of the material types and joint types (*A*B*, p-value=0.00) were statistically significant. Otherwise, the end distance (p-value=0.13) was not statistically significant on joint strength. Thus, interactions of material types and end-distances (*A*C*, p-value=0.96), joint types and end-distances (*B*C*, p-value=0.72), and material types, joint types and end-distances (*A*B*C*, p-value=0.69) did not significantly influence the joint strength. Besides, 94.6% represents the model that explains all the variation in the response variable around the average moment capacity of the joints.

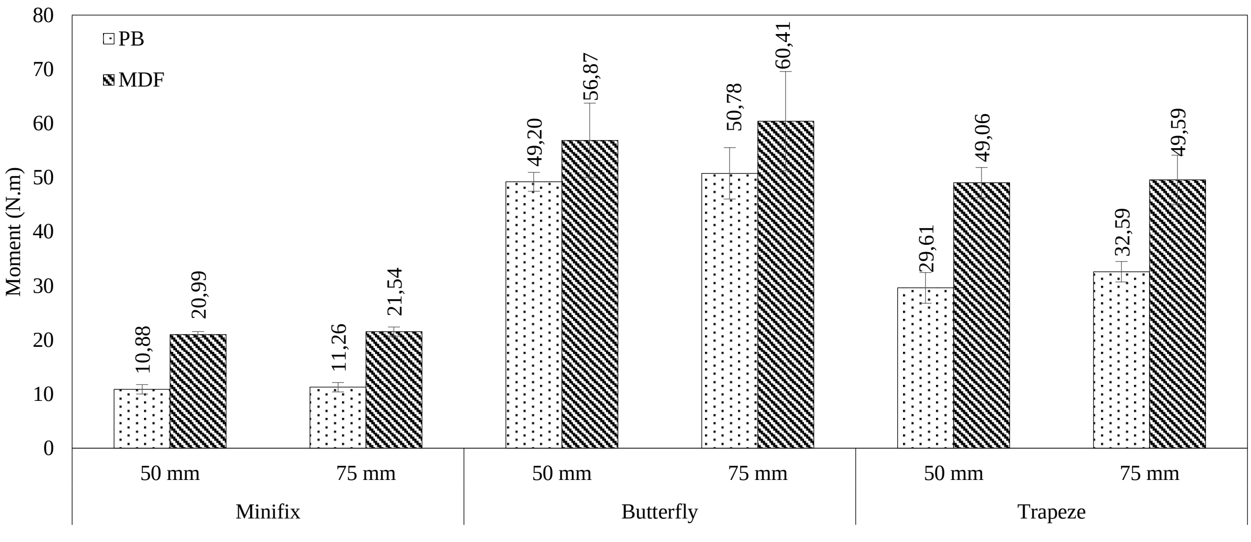

Figure 7. Moment capacity of the corner joints

Table 2. MANOVA for the moment capacity of joint with different parameters

Source	Sum of squares	df**	Mean square	F- value	p-value
Corrected model	17497.72	11	1590.70	95.65	0.00
Intercept	81684.86	1	8168486	4912.19	0.00
Material type (A)	2289.69	1	2289.69	137.69	0.00
Joint type (B)	14882.51	2	7441.25	447.49	0.00
End-distance (C)	38.01	1	38.01	2.28	0.13*
A * B	263.95	2	131.97	7.93	0.00
A * C	0.05	1	0.05	0.00	0.96*
B * C	11.16	2	5.58	0.34	0.72*
A * B * C	12.35	2	6.17	0.37	0.69*
Error	798.19	48	16.63		
Total	99980.77	60			
Corrected total	18295.91	59			
R^2 = 0.956 (Adjusted R^2 = 0.946)					

* shows that were not statistically significant, ** df is degree of freedom, *** The significance level is 0.05

Table 3 shows a Tukey pair-wise mean comparison for the average moment capacity of the joints. According to the results, sample groups with different end distances were not significantly different from each other because, regardless of their material types and joint types, any sample group with different end distances shows the same letters. Joints made of MDF with *butterfly connectors* at the end-distance of 75 mm were significantly different from joints with other connectors. There were no significant differences between joints made of MDF with *trapeze connectors* and PB with *butterfly* connectors. In addition, the results indicated no significant differences among joints made of MDF with *minifix connectors* at each end distance and PB with *trapeze connectors* at the end distance of 50 mm.

Figure 8 shows the distribution of the maximum moment and rotation at the maximum moment of the joints. They showed similar patterns in terms of maximum load and deformation at the maximum loads, as expected. The ratios of the maximum moment and the rotations give the stiffness of the joints, which is depicted in Figure 9. The joints made of MDF with *butterfly connectors* had the highest stiffness. Those of end distances of 50 mm had an average stiffness of 605.51 Nm/rad with a standard deviation of 48.68 Nm/rad. In the case of that end distance was 75 mm, they were 627.51 Nm/rad and 65.34 Nm/rad, respectively. In the case in which PB was used, the average stiffness of the joints with butterfly connectors was 459.85 Nm/rad and 473.64 Nm/rad for end distances of 50 mm and 75 mm, respectively. The lowest average stiffness (15.36 Nm/rad) was observed in the joints made of PB with minifix and an end distance of 50 mm. In the case of using *trapeze connectors* in joints, the average stiffness of joints made of PB was as much as joints made of PB with *butterfly connectors*. Joints were getting slightly stiffer with the increase in end distance from 50 to 75 mm. However, joints made of MDF with *trapeze connectors* decreased by 0.75% with an increase in end distance.

Table 3. Tukey pairwise means comparison results for each sample group

Sample groups*	N	Grouping**				
PB-MFX-50	5	A				
PB-MFX-75	5	A				
MDF-MFX-50	5		B			
MDF-MFX-75	5		B			
PB-TRP-50	5		B	C		
PB-TRP-75	5			C		
MDF-TRP-50	5				D	
PB-BFL-50	5				D	
MDF-TRP-75	5				D	
PB-BFL-75	5				D	
MDF-BFL-50	5				D	E
MDF-BFL-75	5					E

* MFX: Minifix, BFL: Butterfly and TRP: Trapeze, ** There was no significant difference between sample groups having the same letter. The significance level is 0.05.

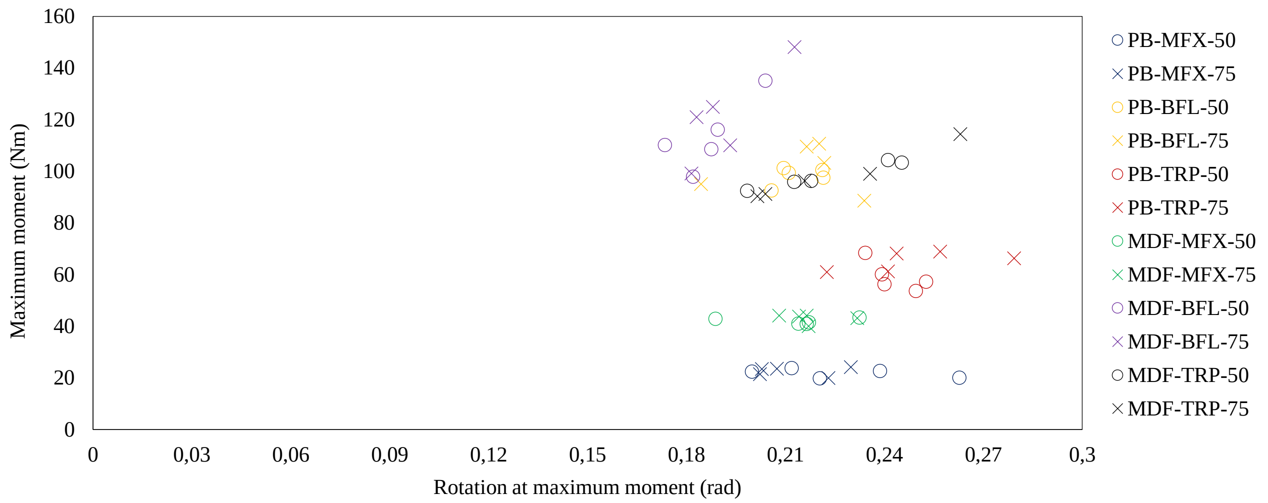

Figure 8. Maximum moments and rotations at the maximum moment of the joints

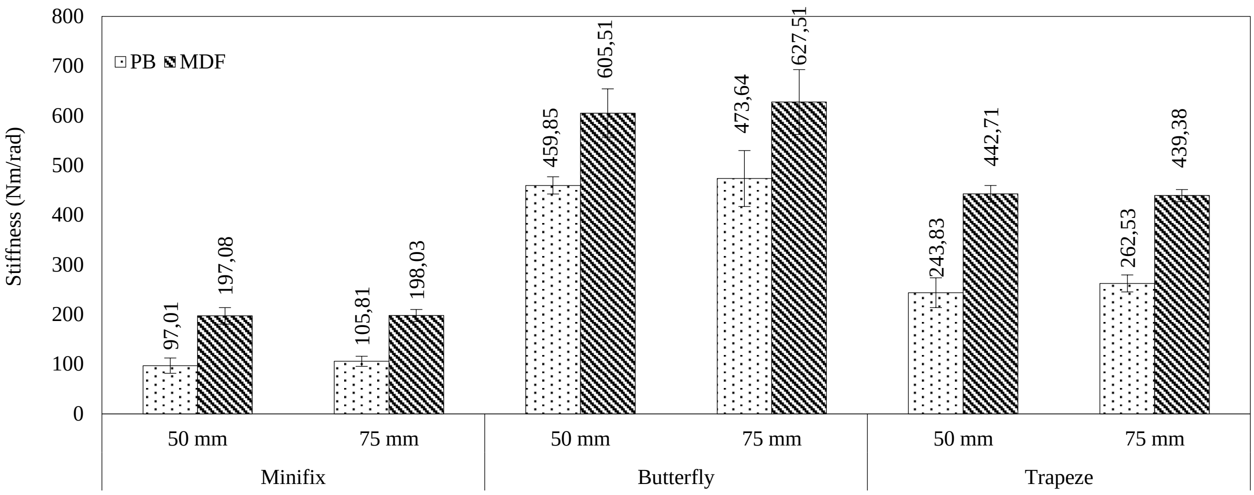

Figure 9. Stiffness of the joints

Table 4 gives MANOVA results of the joint stiffness. According to the results, (i) material types (p-value=0.00), (ii) joint types (p-value=0.00), and (iii) the interaction of the material types and joint types (A*B, p-value=0.00) were statistically significant on the joint stiffness. On the other hand, the end distance (p-value=0.13) was not statistically significant. Thus, interactions of material types and end-distances (A*C, p-value=0.96), joint types and end-distances (B*C, p-value=0.72), and material types, joint types and end-distances (A*B*C, p-value=0.69) did not significantly influence the joint stiffness. Besides, 97.4% represents the model that explains all the variation in the response variable around the average stiffness of the joints.

Table 5 shows a Tukey pair-wise mean comparison for the average stiffness of the joints. According to the results, sample groups with different end distances were not significantly different from each other because, regardless of their material types and joint types, any sample group with different end distances shows the same letters. Joints made of MDF with *butterfly connectors* were significantly different from joints with other connectors. There were no significant differences between joints made of MDF with *trapeze connectors* and PB with *butterfly connectors*. In addition, the results indicated no significant differences among joints made of MDF with *minifix connectors* and PB with *trapeze connectors*.

Table 4. MANOVA for stiffness of joint with different parameters

Source	Sum of squares	df	Mean square	F- value	p-value
Corrected model	1875422.53	11	170492.95	163.73	0.00
Intercept	7185952.10	1	7185952.10	6900.96	0.00
Material type (A)	313598.45	1	313598.45	301.16	0.00
Joint type (B)	1537809.98	2	768904.99	738.41	0.00
End-distance (C)	1546.18	1	1546.18	1.48	0.23*
A * B	21230.77	2	10615.38	10.19	0.00
A * C	195.54	1	195.54	0.18	0.67*
B * C	469.07	2	234.53	0.22	0.79*
A * B * C	572.52	2	286.26	0.27	0.76*
Error	49982.22	48	1041.29		
Total	9111356.85	60			
Corrected total	1925404.75	59			
R^2 = 0.974 (Adjusted R^2 = 0.968)					

* shows that were not statistically significant, ** df is degree of freedom, *** The significance level is 0.05

Table 5. Tukey pairwise mean comparison results for each sample group

Sample Groups	N	Grouping*			
PB-MFX-50	5	A			
PB-MFX-75	5	A			
MDF-MFX-50	5		B		
MDF-MFX-75	5		B		
PB-TRP-50	5		B		
PB-TRP-75	5		B		
MDF-TRP-75	5			C	
MDF-TRP-50	5			C	
PB-BFL-50	5			C	
PB-BFL-75	5			C	
MDF-BFL-50	5				D
MDF-BFL-75	5				D

* There was no significant difference between sample groups having the same letter. The significance level is 0.05.

Average moment capacity and stiffness of joints in the diagonal tension test affected with the material types and connector types used in the joints but there was no significant effect on them by changing end-distances. Due to mechanical properties and density of the material, material type is one of the key indicators for the joint strength and stiffness. Numerous studies showed the effect of the density of material type Smietanska and Mielczarek (2022) indicated that higher densities provided stronger joints and showed it by observing density profile of PB and MDF. Even if it is well-known, the effect of material types should be taken into consideration because of joinery types. In this study, strength and stiffness of the joints made of MDF with minifix were higher by 85-103% compared to those of PB whereas joints with butterfly connector changed by 15-32%. Joint with minifix showed the lower moment capacity than joint with screw and confirmat connector (Yuksel et al., 2015). This trend is consistent with findings from Krzyzaniak et al., who reported that different fastening methods can lead to substantial variations in the bending moment capacities of corner joints (Krzyzaniak et al., 2021). The butterfly and trapeze connectors provide enhanced tensile strength, likely due to their design, which allows for better load distribution and resistance to forces. Furthermore, the ratios of moment capacities between trapeze and minifix connectors highlight the significant advantages of using trapeze connectors, with values ranging from 2.31 to 2.89 for both PB and MDF at different end distances. This finding is corroborated by Derikvand and Eckelman, who noted that the design and type of connector can dramatically influence the performance of wood joints (Derikvand and Eckelman, 2015). The trapeze connectors not only provide higher moment capacities but also enhance the overall structural integrity of the joints, making them suitable for applications requiring high load-bearing capabilities. Similarly, the difference in stiffness between PB and MDF is significant and aligns with the findings of Krzyżaniak et al. (2021), who reported that the material properties of PB limit its performance in load-bearing applications (Derikvand and Eckelman, 2015). The lowest average stiffness observed in joints made of PB with minifix connectors (15.36 Nm/rad) further emphasizes the limitations of this fastening method, which has been shown to provide inferior load distribution compared to other connector types. Interestingly, the stiffness of joints made with trapeze connectors was comparable to that of joints with butterfly connectors when constructed from PB. This suggests that trapeze connectors may offer a viable alternative for enhancing the stiffness of PB joints, potentially compensating for the inherent weaknesses of the material. Although minimal, the slight increase in stiffness observed with the transition from 50 mm to 75 mm end distances indicates that joint design can still be optimized for improved performance.

Moreover, Zhang and Eckelman (1993) and Liu and Eckelman (1998) stated that an increase in the number of connectors on a joint performed better in bending strength until the zone of influences. The joint strength decreased after an increase in the size of the overlapped areas; the connectors were effective. Hence, an increase in the end, distances would reduce after a certain point. However, 50 mm and 75 mm end distances did not significantly affect joint strength in this study. There were increases quantitatively but not statistically significant. In the literature, an increase in end distance from 50 mm to 60 mm (Karaman, 2021), 50 mm to 80 mm (Malkacoglu et al., 2013) and from 30 mm to 60 mm (Simek et al. 2008) increased the joint strength but those of 50 to 70 mm (Karaman, 2021) and 30 to 90 mm (Simek et al., 2008) reduced the joint strength. Therefore, it should be notable to discuss finite element analysis of the joint to examine the stress zone of influences under loading and whether there is an overlapped area or not. The increase in moment capacity with greater end distances, particularly the 10.06% increase observed for PB joints with trapeze connectors. This finding supports the conclusions drawn by Yüksel et al., who emphasized the importance of fastener placement in maximizing joint strength (Yüksel et al., 2014). The slight increase in moment capacity with end distance, while not as pronounced for MDF, still indicates a beneficial effect of increased fastener engagement in the material. The increase in stiffness with the longer end distance is also supported by findings from Yüksel et al. (2014), who noted that increased fastener engagement generally leads to enhanced joint stiffness (Krzyzaniak et al., 2021). However, the decrease in stiffness of MDF joints with trapeze connectors by 0.75% when increasing the end distance from 50 mm to 75 mm is noteworthy. This finding suggests that while trapeze connectors generally enhance joint performance, there may be specific design considerations or material interactions that warrant further investigation. It is essential to explore the underlying mechanisms that contribute to this reduction in stiffness, as understanding these factors could inform future design improvements.

4. Conclusion

This study investigated strength and stiffness of the joint by considering joint types, material types, and end distances. Joints made of MDF and PB with minifix, butterfly, and trapeze connectors were examined under diagonal tensile load, and the consequences below were withdrawn:

- MDF consistently exhibits superior diagonal tensile strength and stiffness relative to PB across all joint types and fastener distances.
- Among the fastening methods, butterfly connectors exhibited the highest tensile strength and stiffness for both PB and MDF, followed by Trapeze connectors and minifix joints with the lowest strength and stiffness.
- An increase in fastener distance from 50 mm to 75 mm generally correlates with a slight increase in tensile strength and stiffness, although these increases were not substantial.

This data underscores the superior mechanical properties of MDF compared to PB in corner joint applications. The butterfly connector configuration was also identified as the most effective joinery method for maximizing strength and stiffness in the diagonal tension test, irrespective of the material used.

References

Dalvand, M., Ebrahimi, G., Tajvidi, M., Layeghi, M., 2014. Bending moment resistance of dowel corner joints in case-type furniture under diagonal compression load. Journal of Forestry Research, 25(4): 981-984. DOI: 10.1007/s11676-014-0481-y

Demirci, S., Diler, H., Kasal, A., Erdil, Y. Z., 2020. Effects of wood species, number of teeth, and adhesive type on moment capacities of box-joints. Bioresources, 15(2): 3136-3146. DOI: 10.15376/biores.15.2.3136-3146

Derikvand, M., Eckelman, C. A., 2015. Bending moment capacity of L-shaped mitered frame joints constructed of MDF and particleboard. Bioresources, 10(3): 5677-5690. DOI: 10.15376/biores.10.3.5677-5690

Hajdarevic, S., Martinovic, S., 2015. The effect of dowel spacing on the stress and strain of case-type furniture corner joint. Proceedings of the 26th DAAAM International Symposium: Intelligent Manufacturing & Automation, 21-24 October, Zadar, Croatia, pp. 391-399.

Karaman, A., 2020. The effect of fastener type (Clamex P14 and Tenso P14) and adhesive type on compression and tension performance. Journal of Bartin Faculty of Forestry, 22(1): 144-152. DOI: 10.24011/barofd.679997

Karaman, A., 2021. An investigation on the effects of wooden species of dowels and the end distance of catch connectors (Clamexp14) on the bending moment of L-type corner joints for RTA (ready to assemble) furniture. Wood and Fiber Science, 53(1): 48-61.

Kasal, A., Smardzewski, J., Kuskun, T., Guray, E., 2023. Analyses of L-type corner joints connected with auxetic dowels for case furniture. Materials, 16(13): 4547. DOI: 10.3390/ma16134547

Klos, R., Langova, N., 2023. Determination of reliability of selected case furniture constructions. Applied Sciences, 13: 4587. DOI: 10.3390/app13074587

Krzyzaniak, L., Smardzewski, J., 2019. Strength and stiffness of new designed externally invisible and demountable joints for furniture cases. Engineering Structures, 199: 109674. DOI: 10.1016/j.engstruct.2019.109674

Krzyzaniak, L., Smardzewski, J., 2021. Impact damage response of L-type corner joints connected with new innovative furniture fasteners in wood-based composites panels. Composite Structures, 255: 113008. DOI: 10.1016/j.compstruct.2020.113008

Kuskun, T., Kasal, A., Caglayan, G., Ceylan, E., Bulca, M., Smardzewski, J., 2023. Optimization of the cross-sectional geometry of auxetic dowels for furniture joints. Materials, 16: 2838. DOI: 10.3390/ma16072838

Liu, W. Q., Eckelman, C. A., 1998. Effect of number of fasteners on the strength of corner joints for cases. Forest Products Journal, 48(1): 93-95.

Malkacoglu, A., Cetin Yerlikaya, N., Cakıroglu, F. L., 2013. Effects of number and distance between dowels of ready-to-assemble furniture on bending moment resistance of corner joints. Wood Research, 58(2): 671-680.

Petrova, B., Jivkov, V., Yavorov, N., 2023. Possibilities for efficient furniture construction made of thin and ultra-thin materials by using mitre joints. Materials, 16: 6855. DOI: 10.3390/ma16216855

Simek, M., Haviarova, E., Eckelman, C. A., 2008. The end distance effect of knock-down furniture fasteners on bending moment resistance of corner joints. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunnensis, 56(2): 203-210.

Smietanska, K., Mielczarek, M., 2022. Strength properties of furniture corner joints constructed with different wooden connectors and wood-based materials. Annals of Warsaw University of Life Sciences - SGGW, Forest and Wood Technology, 118: 56-66.

TS EN 310, 1999. Ahşap esaslı levhalar-Eğilme dayanımı ve eğilme elastikiyet modülünün tayini, TSE, Ankara.

TS EN 323, 1999. Ahşap esaslı levhalar – Birim hacim ağırlığının tayini. TSE, Ankara

TS EN 326-1, 1999. Ahşap esaslı levhalar – Numune alma, kesme ve muayene. TSE, Ankara

Yerlikaya, N. Ç., Aktaş, A., 2012. Enhancement of load-carrying capacity of corner joints in case-type furniture. Materials & Design, 37: 393-401.

Yuksel, M., Kasal, A., Erdil, Y. Z., Acar, M., Kuskun, T., 2015. Effects of the panel and fastener type on bending moment capacity of L-type joints for furniture cases. ProLigno, 11(4): 426-431.

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