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THE RELIABILITY OF CASE FURNITURE: EFFECTS OF MATERIAL TYPES AND NUMBER OF FASTENERS

Elif KORKMAZ TETİK
Graduate Student – Bursa Technical University
Department of Forest Industry Engineering, Bursa Technical University, 16310 Bursa, Turkey
Product Development Engineer – Design Center, Cilek
Address: Çilek Plant, 16420, Bursa, Turkey
E-mail: elif.korkmaz@cilek.com

Kübra EVBAŞI
Graduate Student – Bursa Technical University
Department of Forest Industry Engineering, Bursa Technical University, 16310 Bursa, Turkey
E-mail: kubraevbasi8@gmail.com

Murat YAREN
Graduate Student – Bursa Technical University
Department of Forest Industry Engineering, Bursa Technical University, 16310 Bursa, Turkey
Senior Engineer – Surface Finishing Supervisor, Kastamonu Entegre
Address: MDF & Particle Board Plant, 10100, Balıkesir, Turkey
E-mail: murat.yaren@keas.com.tr

Mesut UYSAL*
Assoc. Prof. Dr. – Bursa Technical University
Department of Forest Industry Engineering, Bursa Technical University, 16310 Bursa, Turkey
E-mail: mesut.uysal@btu.edu.tr

Abstract:
This study investigates the structural reliability of case furniture considering the moment capacity of corner joints subjected to diagonal tensile and compression loading. Medium-density fiberboard (MDF) and particleboard (PB) panels were assembled using metal butterfly fasteners with two and three-fastener configurations. Moment resistance and rotational stiffness of L-type corner joints were experimentally determined. A stiffness method was developed in MATLAB to calculate internal joint moments under external loads of 100, 150, and 200 N. Assuming normally distributed strength properties, the probability of failure for each joint was computed, and overall case furniture reliability was evaluated using a series system model. Results indicated that joints constructed from MDF exhibited significantly higher moment capacity and rotational stiffness than those constructed from PB. Diagonal tensile loading produced substantially greater moment resistance than compression loading due to internal fastener engagement mechanisms. Reliability analysis revealed that overall case furniture performance is governed by the weakest joint, confirming the weakest-link behavior of series systems. At 100 N, case furniture constructed from MDF with three fasteners demonstrated near-deterministic reliability (R_{SS} ≈ 99.9%), whereas case furniture constructed from PB with two fasteners showed drastic reliability reduction (R_{SS} ≈ 1.4%). Reliability degradation under increasing load was nonlinear, indicating that single-joint strength alone cannot predict system-level performance. Relocating the fastener from a compression-dominated to a tension-dominated stress region significantly improved both joint and system reliability. The findings demonstrate that material type, fastener quantity, and fastener positioning critically influence load transfer mechanisms, failure initiation zones, and structural reliability of case furniture.

Key words: *case furniture, reliability, moment capacity, rotational stiffness and butterfly fasteners.*

INTRODUCTION

The reliability of corner joints in case furniture is vital to ensure structural integrity and durability in furniture constructions. These joints are often the critical points of failure owing to subjected to mechanical loads and environmental conditions. Understanding the mechanical performance, behavior, and potential failure points of these joints is fundamental to develop more reliable furniture.

Numerous studies have been conducted on joint strength. (Hu et al. 2023) shows that factors such as geometric parameters and material types affect joint stiffness, strength, and failure modes. The bending moment capacity of corner joints can be directly related to the design and joints, underscoring the need for

*Corresponding author

rigorous testing and optimization of these components (Šimek et al. 2008). Kasal et al. (2016) contributed to a greater understanding of how joint configurations can be optimized for increased reliability. Besides, Uysal and Haviarova (2018) introduced probabilistic approaches to assess the reliability of dowel joints, emphasizing the importance of employing methods like tolerance intervals to enhance structural safety. Kasal et al. (2020) and Ceylan et al. (2024) observed the auxetic dowels - material structures with unique deformation properties – for advancement in joint design altering behavior of fasteners under imposed load. Kasal et al. (2025) examined newly developed and 3D printed fasteners made of PLA, ASA and PETG and resulted that these fasteners did not have much strength as much as minifix/dowel joints which are commonly used in furniture industry. The strength and rotational stiffness of the corner joints provides an insight about failure mechanism and joint behavior but not fully understanding of overall reliability and strength of the furniture construction.

The investigation into the reliability of corner joints in case furniture serves several significant purposes, impacting both practical furniture design applications and broader theoretical frameworks in engineering design of furniture. Smardzewski (2009) exhibited the how reliability of case furniture influenced by changing fastener type; namely, 6 mm-dowel, 8-mm dowel and confirmat, and resulted that confirmat fasteners provided higher reliability compared to others. Besides, the incremental rate in reliability of case furniture was 81.94% by altering fastener in corner joint from 6 mm - to 8 mm - dowels. Kłos et al. (2018) conducted a comparative reliability analysis of different joint types and concluded that combination of joinery systems at one corner joints provided greater reliability levels and the failure rate of the single joints significantly impacts the reliability of the overall furniture construction, so joint design is a critical factor in furniture durability. Similarly, Kłos and Langová (2023) emphasized that increase the number of fasteners in one corner joints or combination of joinery systems provided parallel systems in corner joints which enhanced the reliability of the corner joints; thereby overall reliability of the case furniture. Uysal (2024) indicated that it was vital to measure reliability considering joint types rather than overall furniture frames. These studies highlighted significance of the reliability of corner joints in case furniture by providing insights necessary to ensure safety, enhancing structural integrity, inciting design innovation, and promoting sustainability.

In this study, it was aimed to evaluate how material used in the furniture construction and joinery systems can alter the moment capacity, rotational stiffness and reliability of corner joints, and reliability of the overall case furniture. In doing so, the research objectives were to (i) experimentally determine moment capacity and rotational stiffness of the corner joints under diagonal tensile and compression loads, (ii) compare the mechanical performance of the corner joints constructed from MDF and PB with two and three fasteners, (iii) to calculate joint-level probability of failure assuming normal distribution of joints strength and (iv) to determine overall case furniture reliability using a series system model.

MATERIALS AND METHODS

Materials

In this study, 18-mm-thick PB and MDF panels were used to assess joint strength and rigidity. Metal butterfly fasteners were used to construct L-shaped corner joints. Some material properties of the PB and MDF panels were given in Table 1.

Table 1

Material properties of the materials (Karatay et al. 2024)

Material	Density (g/cm^3)	Bending Strength (MPa)	Modulus of Rupture (MPa)
PB	0.66	13.10	2520.32
MDF	0.71	36.89	3419.00

Method

Sample Preparation

All specimens were cut from PB and MDF material with dimensions of 18×182×300 mm and 18×200×300 mm for butt and face members, respectively. The end distances were 50 mm from the edges of the members for the fasteners, which were positioned as shown in Fig. 1. Three replications were prepared for each sample group; accordingly, 24 specimens were prepared using a three-factor experimental design with 2 material types, 2 numbers of fasteners, and 2 experimental tests.

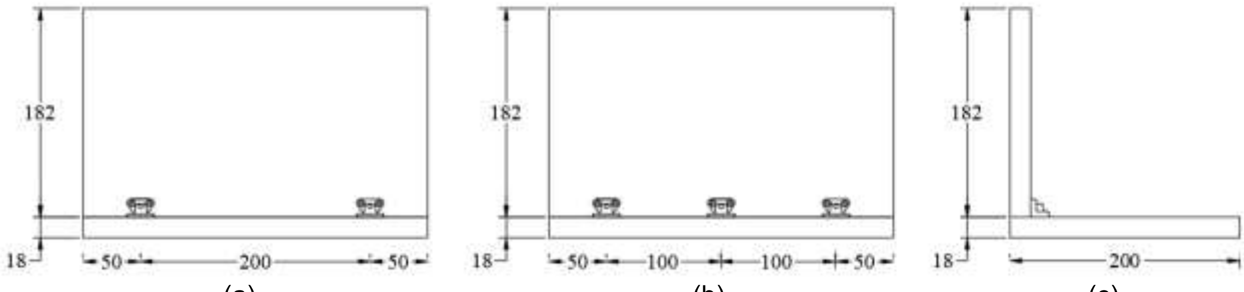


Fig. 1.
Test specimen configurations
a – 2 fasteners; b – 3 fasteners; c – Side view.

Diagonal tensile and compression tests

All tests were conducted on the Shimadzu universal testing machine at a rate of 10 mm/min until a non-recoverable failure occurred (Fig. 2). The moment and rigidity of the corner joints in the diagonal tensile (equations 1 to 8) and compression (equations 9 to 15) tests were calculated (Krzyżaniak et al. 2021).

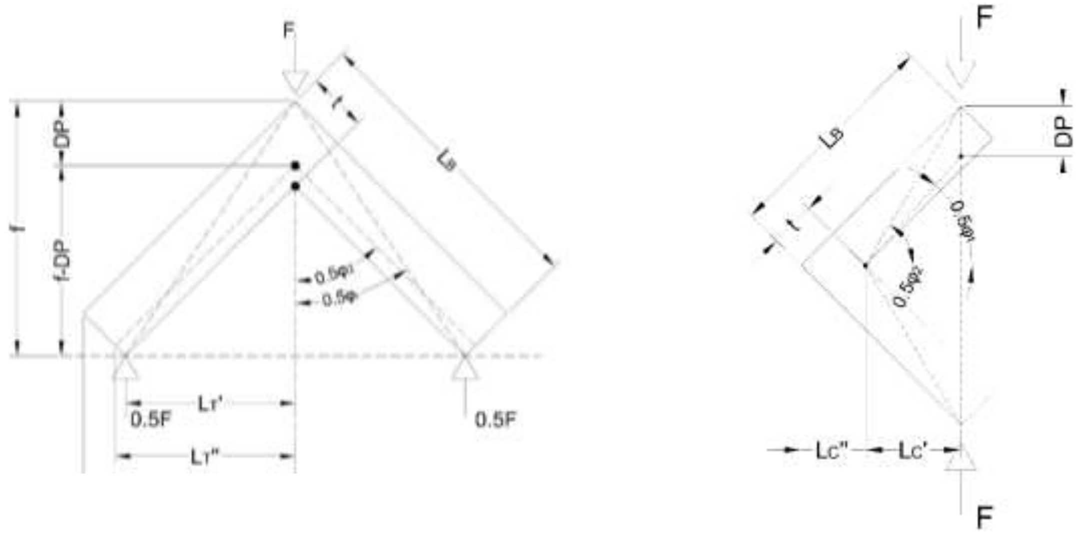


Fig. 2.
Test configurations
a – Diagonal tensile test; b - Diagonal compression test.

$$M_T = 0.5 \times F_{ult} \times L'_T \quad (1)$$
$$K_T = \frac{M_T}{\Delta\varphi} \quad (2)$$
$$\Delta\varphi = \varphi_2 - \varphi_1 \quad (3)$$
$$L'_T = (L_B - t) \times \cos 45 \quad (4)$$
$$0{,}5\varphi_1 = \tan^{-1}\left(\frac{L'_T}{f}\right) \quad (5)$$
$$0{,}5\varphi_2 = \tan^{-1}\left(\frac{L''_T}{f-DP}\right) \quad (6)$$
$$f = L'_T + (\sin 45 \times t) \quad (7)$$
$$L''_T = \sqrt{(L'_T)^2 + f^2 - (f-DP)^2} \quad (8)$$

where: M_T is the moment in the diagonal tensile test, in N·m
F_{ult} is the ultimate load in the diagonal tensile test, in N
L_T' is the moment arm in the diagonal tensile test, in m
$\Delta\varphi$ is the change in angle after tensile loading, in rad
DP is the displacement after tensile loading, in rad

$$M_C = F_{ult} \times L'_C \tag{9}$$
$$K_C = \frac{M_C}{\Delta\varphi} \tag{10}$$
$$\Delta\varphi = \varphi_1 - \varphi_2 \tag{11}$$
$$L'_C = L_B \times \cos 45 - L''_C \tag{12}$$
$$L''_C = t\sqrt{2} \tag{13}$$
$$0{,}5\varphi_1 = \tan^{-1}\left(\cos 45 \times \frac{L_B}{L'_C}\right) \tag{14}$$
$$0{,}5\varphi_2 = \tan^{-1}\left(\cos 45 \times \frac{L_B - DP}{\sqrt{t^2 + (L_B - t)^2}}\right) \tag{15}$$

where: M_C is the moment in the diagonal compression test, in N·m
F_{ult} is the ultimate load in the diagonal compression test, in N
L_C' is the moment arm in the diagonal compression test, in m
$\Delta\varphi$ is the change in angle after compressive loading, in rad
DP is the displacement after compressive loading, in rad

Reliability Measurement of Case Furniture

A case-furniture construction comprising six corner joints was analyzed using the stiffness matrix method implemented in MATLAB, based on Equation (16). External loads of 100 N, 150 N, and 200 N were applied in accordance with the loading configuration illustrated in Fig. 3. The bending moment developed at each joint was calculated, and these moment values were subsequently used to evaluate the overall structural reliability of the case furniture system.

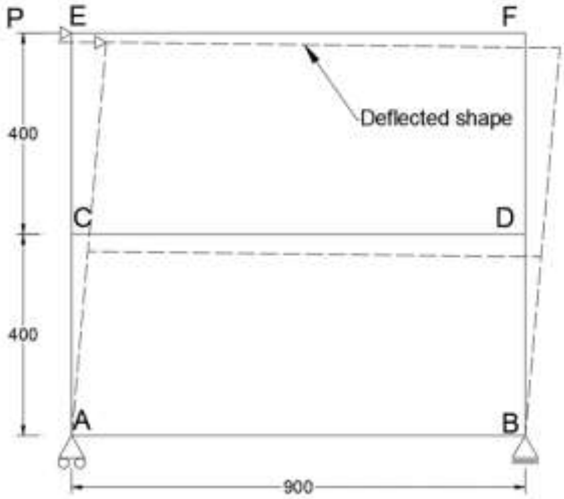


Fig. 3.
Defined case furniture configuration (in mm).

$$\{Q\} = [K] \times \{D\} \tag{16}$$

where: Q is the force vectors, in N or N·m
K is the structure stiffness matrix
D is the planar displacement vectors, in m, or rotational displacement vectors, in rad

In this study, data were assumed to be normally distributed to calculate the probability of failure (P_f) for each joint in the case furniture. Uysal (2024) previously described how to calculate *Pf* for furniture frames using the cumulative density function *Φ(z)*, as explained in (Chang 2015). Furthermore, the overall reliability of the case furniture was calculated using equation 17. Each joint in the case furniture was mechanically arranged in a series configuration, such that the overall structural performance and reliability of the system were governed by the weakest joint element.

$$R_{SS} = \prod_{i=1}^{n} R_i \tag{17}$$
$$R = 1 - P_f \tag{18}$$
$$P_f = \phi(z) \tag{19}$$

where; R_{ss} is the overall reliability of the case furniture
R_i is the reliability of i^{th} joint (i=1,2,3,4,5 and 6)
n is the number joint in case furniture (n=6)

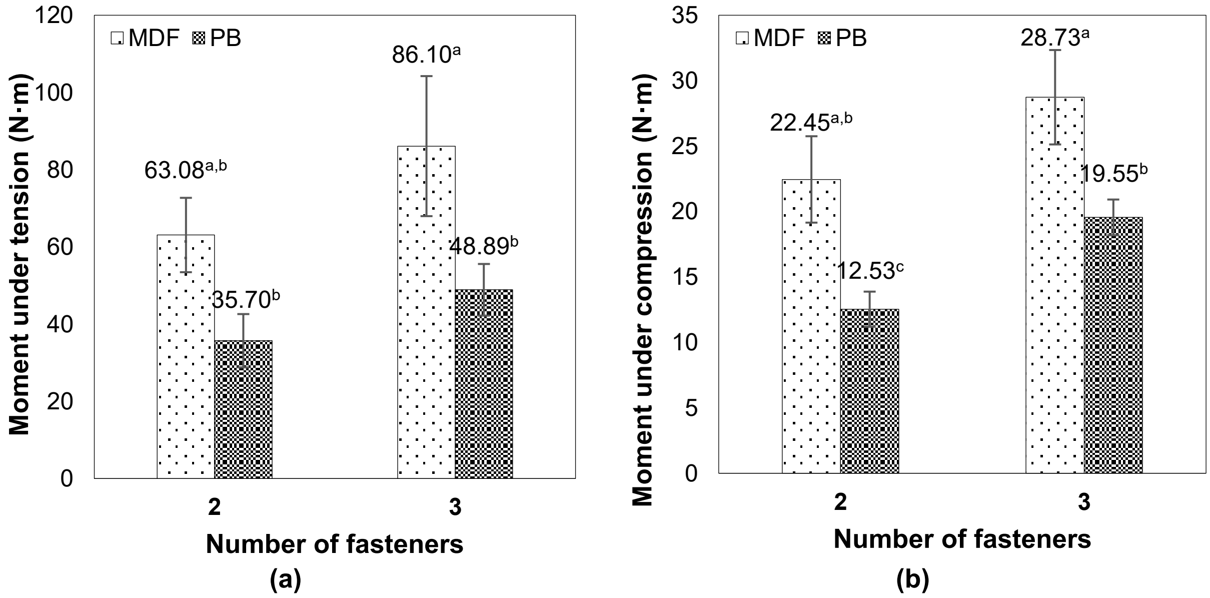
Statistical Analysis

Data was collected for the presence of statistical significance among all sample groups through Tukey pair-wise comparisons for joint sample groups were examined in SPSS 22.

RESULTS AND DISCUSSION

Strength and Rigidity of Corner Joints

The test results were given in Fig. 4. According to the results, the highest average moment in the diagonal tensile strength was 86.10 N·m for corner joints constructed from MDF with 3 fasteners, followed by those of 2 fasteners with an average of 63.08 N·m (Fig. 4.a). Whereas the average moment in the diagonal tensile test for corner joints constructed from PB were lower by approximately 43% than those of MDF as former studies demonstrated (Smardzewski et al. 2016; Taghiyari et al. 2017; Krzyżaniak et al. 2021; Kasal et al. 2023). Due to fact that MDF is denser material than PB which provides better load distribution and screw holding capacity, joints constructed from MDF performed better. Additionally, the moment capacity under tension loads enhanced by 37% with an increase in number of fasteners. The spatial distance between two fasteners significantly affect the load distribution owing to reduce local stress concentration which leads to joint failure. Kasal (2008) and Simek et al. (2010) depicted increase in moment capacity with a higher number of fasteners for screw and dowels, respectively. According to Tukey pair-wise mean comparison results, moment capacity under tensile loads for joint constructed from MDF with three fasteners significantly different from those of PB while there is no statistically difference among joints constructed from MDF with two fasteners and both joint constructed from PB with two and three fasteners. The same phenomena were observed for the moment capacity under compression loads for corner joints with butterfly fasteners. However, the moment capacity of the corner joints under compression loads were approximately 1/3 of those of tensile loads (Fig. 4.b). Kasal et al. (2023) resulted that the failure loads were twice or third times greater than those of compression depending on cross sectional of auxetic dowels. The higher joint strength observed under diagonal tensile loading can be explained by the internal positioning of the butterfly fastener within the corner region. During tensile loading, separation initiates at the inner corner, where the fastener is actively engaged in resisting opening stresses and transferring loads across the joint interface. In contrast, under diagonal compression loading, separation begins at the outer edge of the corner, where the fastener does not initially contribute to resistance; consequently, early-stage separation occurs with limited restraint due to the stress distribution, resulting in lower load capacity.



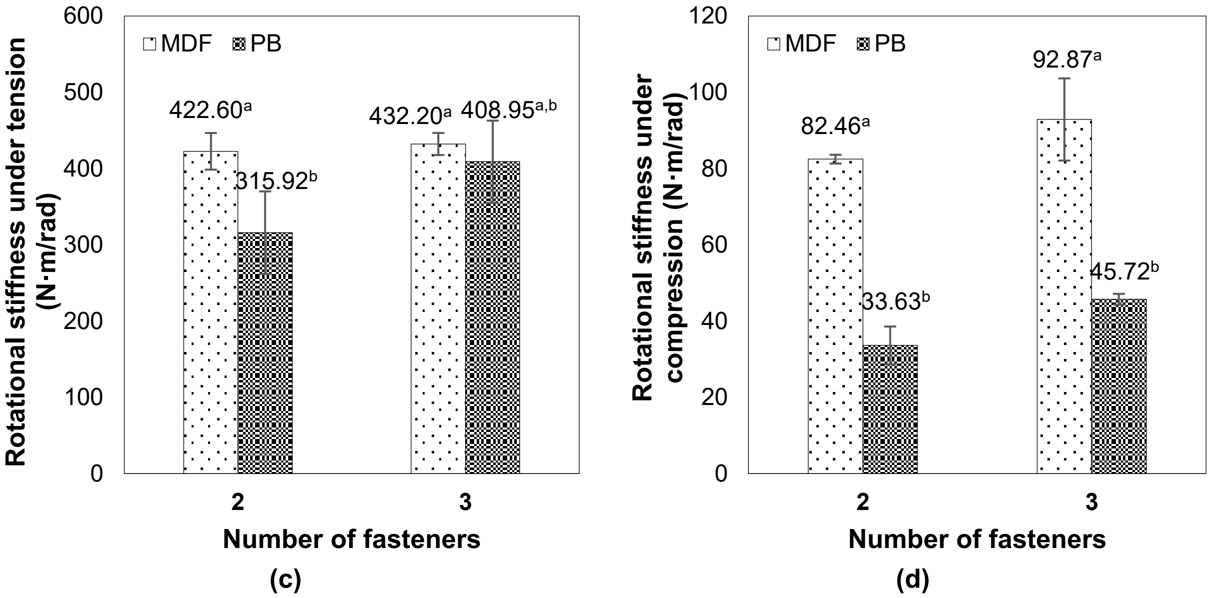


Fig. 4.
Strength and Rigidity of the Corner Joints
a – Moment in diagonal tensile test; b - Moment in diagonal compression test; c - Rigidity in diagonal tensile test; d - Rigidity in diagonal compression test (The same letters show that means are not statistically different).

The rotational stiffness of the corner joints was given in Fig. 4.c and d. According to the results, in both tensile and compression tests, joints constructed from MDF provided higher rotational stiffness than those of PB due to the fact that MDF is a denser, stronger, and more rigid material than PB. In addition, rotational stiffness was higher in the diagonal tensile test than in the compression test; correspondingly, internal positioning of butterfly fasteners in the corner joints crucially affected the displacement point at ultimate load level. Therefore, rotational stiffness under compression loads was incredibly lower. According to the Tukey pair-wise mean compression test, materials used in the corner joints were statistically significant but number of fasteners were not in the both diagonal tension and compression tests.

Overall Reliability of Case Furniture

The moment that occurred on each joint is given in Table 2. After imposing loads (P=100 N, 150 N and 200 N) defined as Fig. 3, the highest moments occurred on on the mid shelf-to-side panels joints. Depending on deflected shape and internal positioning of the fasteners, A-D-F joints were subjected to compression load while B-C-E joints were subjected to tensile loads.

Table 2

Moments on the joints of the case furniture

Load (N)	Moment at joints (N·m)					
	A	B	C	D	E	F
200	23.52	23.54	32.94	32.94	23.54	23.52
150	17.64	17.66	24.71	24.71	17.65	17.64
100	11.76	11.77	16.47	16.47	11.77	11.76

The overall reliability of the case furniture was evaluated using a series system model based on the moments on the joints of case furniture and moment capacity of the joints subjected to diagonal tension and compression loads (Table 3). The weakest joint was the Joint-D which governed system failure. Even when five joints displayed reliabilities above 95-99%, a single joint with markedly lower reliability reduced the overall system reliability to near-zero values. This behavior confirms the structural sensitivity of case furniture to local corner joint performance under moment loading because a furniture construction performs as much as performance of the weakest joint (Smardzewski 2009). At 100 N load level, case furniture constructed from MDF panels demonstrated higher performance compared to those of PB. The case furniture constructed from MDF with fasteners exhibited near-deterministic behavior (R_{ss} = 99.89%), whereas reliability of those of 2 fasteners reduced moderately (R_{SS} = 94.54%). In contrast, PB with two fasteners yielded a drastic reliability decrease (R_{SS} = 1.42%), despite adding the third fasteners individually increased reliability to 92.53%.

Table 3

Reliability of each joint and case furniture

Material	Number of fasteners	Load (N)	Reliability of each joint in the case furniture						Overall reliability of case furniture (R_{SS})
			R_A	R_B	R_C	R_D	R_E	R_F	
MDF	2	100	99.89%	99.99%	99.99%	94.75%	99.99%	99.89%	94.54%
		150	90.06%	99.99%	99.99%	29.25%	99.99%	90.09%	23.73%
		200	39.58%	99.99%	99.85%	1.23%	99.99%	39.65%	0.19%
	3	100	99.99%	99.99%	99.99%	99.90%	99.99%	99.99%	99.89%
		150	99.71%	99.99%	99.96%	82.16%	99.99%	99.71%	81.64%
		200	88.68%	99.97%	99.80%	19.46%	99.97%	88.72%	15.27%
PB	2	100	66.70%	99.97%	99.66%	3.21%	99.97%	66.78%	1.42%
		150	1.06%	99.43%	93.31%	0.01%	99.43%	1.07%	0.01%
		200	0.01%	95.22%	64.10%	0.01%	95.23%	0.01%	0.01%
	3	100	99.99%	99.99%	99.99%	92.53%	99.99%	99.99%	92.53%
		150	80.41%	99.99%	99.97%	3.40%	99.99%	80.49%	2.20%
		200	7.21%	99.98%	98.38%	0.01%	99.98%	7.25%	0.01%

Even though subjected load increased linearly with an incremental rate of 50 N (P = 100N, 150N and 200N), reliability for all case furniture configuration was changed non-linearly which shows that comprehending behavior of single-joint mechanism cannot wholly reflect the behavior of the case furniture. The overall reliability of the case furniture constructed from MDF with 2 fasteners reduced from 94.54% to 0.19% with an increase of load level from 100 N to 200 N. Those of 3 fasteners were 99.89% to 15.27%. The reduction rates in overall reliability of the case furniture were 99.79% and 89.71% for joints with 2 and 3 fasteners, respectively. Additionally, joints constructed from PB showed drastic reliability collapse beyond 100 N, with system reliability approaching zero at 150 N and 200 N, regardless of number of fasteners.

Furthermore, the initial position of the butterfly fastener in Joint-D, identified as the weakest joint within the series system, was relocated from the lower corner of the shelf to the upper corner. This modification altered the load distribution acting on the joint, shifting the dominant loading mode from diagonal compression to diagonal tension. The corresponding changes in the reliability of Joint-D (R_D) and the overall system reliability of the case furniture (R_{SS}) are presented in Table 4. The results indicate that repositioning the fastener significantly enhanced reliability, particularly at higher load levels. For MDF constructions, both two- and three-fastener configurations exhibited a marked increase in R_D and, consequently, in R_{SS} as load level increased. In contrast, PB panels demonstrated reliability improvement under this modification only in the three-fastener configuration. Notably, a substantial increase in overall reliability was observed for PB with two fasteners at the 100 N load level, indicating a strong sensitivity of system performance to fastener placement under loading conditions. These findings highlight the critical interaction between material used in construction, number of fasteners, and fastener positioning relative to the moment-induced load distribution in corner joints. The results confirm that joint configuration and fastener location directly influence load transfer mechanisms and failure initiation zones, thereby governing the structural reliability of case furniture designed as a series system.

Table 4

Reliability of weakest joint and case furniture when altering the initial position of fasteners

MDF						
Number of Fastener	**2**			**3**		
Load (N)	**100**	**150**	**200**	**100**	**150**	**200**
R_D in comp.	94.75%	29.25%	1.23%	99.90%	82.16%	19.46%
R_D in tension	99.99%	99.99%	99.85%	99.99%	99.96%	99.80%

Difference	6%	242%	8018%	0%	22%	413%
R_{SS} in comp.	94.54%	23.73%	0.19%	99.89%	81.64%	15.27%
R_{SS} in tension	99.62%	81.12%	15.67%	99.79%	99.33%	78.47%
Difference	5%	242%	8147%	0%	22%	414%
PB						
Number of Fastener	**2**			**3**		
Load (N)	**100**	**150**	**200**	**100**	**150**	**200**
R_D in comp.	3.21%	0.01%	0.01%	92.53%	3.40%	0.01%
R_D in tension	99.66%	93.31%	64.10%	98.38%	99.97%	99.99%
Difference	3005%	933000%	640900%	6%	2840%	999800%
R_{SS} in comp.	1.42%	0.01%	0.01%	92.53%	2.20%	0.01%
R_{SS} in tension	28.43%	0.01%	0.01%	98.38%	64.68%	0.51%
Difference	1902%	0%	0%	6%	2840%	5000%

CONCLUSION AND RECOMMENDATIONS

In this study, strength and rigidity of the corner joints and reliability of individual joints and overall reliability of case furniture were examined. This study confirms that structural reliability of case furniture is governed by the mechanical performance of its weakest corner joint; namely, the weakest joint drastically reduces overall system reliability even if others have higher reliability. Joints constructed from MDF provided superior moment capacity and rotational stiffness compared to PB, leading to significantly higher reliability levels. Increasing the number of butterfly fasteners enhanced joint strength and improved reliability under moderate loading; however, reliability degradation under higher loads was nonlinear and severe, especially for PB constructions. Diagonal tensile loading resulted in greater moment resistance than compression loading due to internal fastener engagement within the joint interface. Repositioning the fastener to a tension-dominated stress region markedly improved both joint reliability (R_D) and overall system reliability (R_{SS}), highlighting the critical importance of fastener placement in corner joint design. The findings demonstrate that joint configuration, material properties, and fastener layout directly govern load transfer mechanisms and failure initiation behavior, thereby determining the structural reliability of case furniture.

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