THE EFFECTS OF WOODEN DOWEL SPECIES AND THE END DISTANCE OF MINIFIX FASTENER ON THE SHEAR FORCE CAPACITY FOR H-TYPE FURNITURE JOINTS

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Abstract. Effects of the wooden dowel species and edge distances were studied relative to the shear force capacities of H-type furniture joints with minifix fastener under loadings. Melamine-coated medium-density fiberboard (MDF-Lam), minifix fasteners, and wooden dowels were used for specimens as used in the furniture industry. H-type joint specimens were tested in shear force. These compression tests were applied to 60 pieces of test samples prepared for this study based on the principles of ASTM D 1037-06 (2010). According to the results, the highest shear force capacities were obtained for the beech dowel. According to edge distances from end distances, the highest shear force capacities were obtained at 72 mm distance from the edge. In the manufacturing of wood composite based H type furniture, the highest shear force capacity values were obtained with the edge distance of 72 mm with an oak dowel combination (1649 N), while the edge distance of 90 mm with a beech dowel combination (1405 N) gave the lowest shear force capacity values. Furthermore, it was concluded that oak dowel as a substance and the distance 72 mm from the edge as distance could be recommended.

Keywords: Shear force capacity, H-type joint, end distance, minifix fastener, wooden dowel.

INTRODUCTION

Ready-to-assemble (RTA)-type furniture is an important product and is used extensively in offices, homes, and other rooms for essential elements of home furnishings. The furniture typically is constructed from particleboard and medium-density fiberboard coated with colored melamine or wood veneers (Pepke 1988). Melamine-coated medium-density fiberboard (MDF-Lam) is the most common wood-based panel product used in the construction of RTA cabinet furniture (Karaman 2020).

RTA-type furniture has been used for almost half a century (Zhang et al 2005). Minifix fasteners are placed near the ends of the members that are connected to provide 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 minifix fastener 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 that allows the development of maximum joint strength (Simek et al 2010).

Liu and Eckelman's (1998) study on corner joints clearly demonstrated that for either glued dowels or screws, the bending moment capacity of the joints decreased as the spacing between the fasteners decreased below 60 mm. Tankut (2005) similarly claimed that the maximum moment capacity per dowel was obtained in the joints when the spacing between the dowels was at least 96 mm. Norvydas et al (2005) investigated the effect of the distances between the dowel and the edge of the piece in glued joints with dowels. They chose distances between the dowel and the

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edge of the piece of 20, 25, 30, 35, 40, 45, 50, 55, and 60 mm and reported that joint resistance was highest when the distance between the dowel and the part edges was 55 mm. Simek et al (2008) investigated the effect of the end distance of cam-lock fasteners on the bending moment resistance of knock-down corner joints and found that an end distance of 60 mm from the member edges performed best. Simek et al (2010) investigated the effect of the end distance of cam-lock fasteners and nonglued wooden dowels on the splitting and bending moment resistance, respectively, of RTA corner joints. The tests showed that cam connectors located 60 mm from the edge of the joint had the highest moment capacity. Malkocoglu et al (2013) investigated the effects of the number and distance between the dowels of RTA furniture on bending moment resistance. Their results showed that bending moment capacity increased when dowel spacing increased from 96 to 160 mm. Malkocoglu et al. (2014) observed that strength was increased by decreasing end distances and that 50 and 60 mm end distances were stronger than 70 and 80 mm. As a result, the front and rear stop values were recommended as equal and 60 mm.

Karaman (2020) examined 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. The highest bending moment resistance was obtained from an end distance of 60 mm.

Limited information is available on the effects of loading type and wooden dowel species on the shear force performance of minifix-connected H-type furniture joints.

The shear strength performance of box furniture H-type joining elements indicates that plastic dowels in box furniture assemblies are not suitable for strength (Kasal et al 2012). Yıldırım et al (2020) studied the performance of H-type furniture joints prepared using wood-based materials (MDF-Lam and YL-Lam) and demountable type connectors against shear forces. Karaman (2019) determined the shear strength performance of H-type furniture joints with disassembled type connectors (Clamex P14 and Tenso P14).

Hypothesis of this Research

1. H0: There is a significant relationship between wooden dowel species and the end distance of minifix fasteners on the shear force performance of H-type furniture joints.
2. H1: There is no significant relationship between wooden dowel species and the end distance of minifix fasteners on the shear force performance of H-type furniture joints.

The objective of this study was to investigate the effects of different wood species of dowels and the end distance of minifix fasteners on the shear force performance of H-type furniture joints. This study will be beneficial for the users of minifix fasteners.

MATERIALS AND METHODS

All joint specimens were prepared from 18-mm-thick MDF-Lam which is used extensively in the furniture industry and was purchased from a local merchant in Usak, Turkey.

In this study, Minifix fasteners were obtained from a local dealer at the Häfele Concept Design Center, Istanbul, Turkey. Dowels (8 mm in diameter and 36 mm long) were chosen to be used with the Minifix fasteners. The dowels were prepared from beech (*Fagus orientalis* Lipsky) and oak (*Quercus petraea* Lieble) as shown in Fig 1.

MDF-Lam panels were tested for MC, density, MOR, and MOE according to TS EN 323 (1999), TS EN 322 (1999), TS EN 310 (1999), and ASTM D1037 (2006), respectively. Wood materials were tested for MC, density, MOR, and MOE 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 H-Type Furniture Joints

The wooden dowel materials were conditioned at $20 \pm 2°C$ and $65 \pm 3\%$ RH until their weight

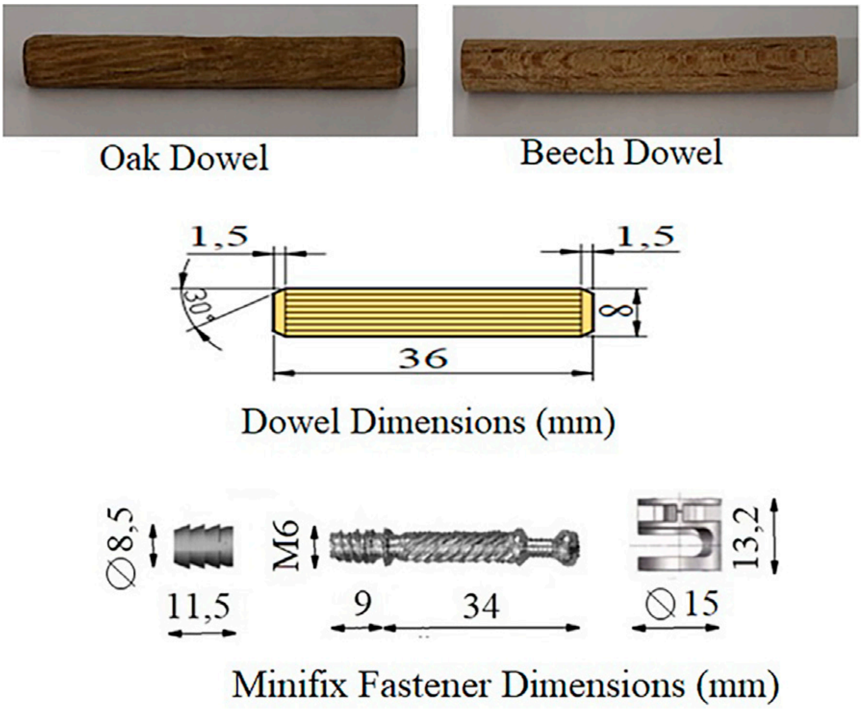

Figure 1. Wooden dowel species and Minifix fastener used in this study (dimensions in mm).

became stable. For making dowels, 1000 × 10 × 10 mm pieces were cut from beech and oak to produce 8-mm diameter and 36-mm long dowels using a dowel machine. The configuration of the H-type joint specimens used for this study is shown in Fig 2. The test specimens consisted of three members: two vertical and one horizontal. The vertical members were 270 × 300 mm and the horizontal element was 270 × 400 mm, which were joined together by specified connectors. Based on the findings from assembly plans, the minifix fasteners were placed close to the end of the joint members. Specimens with three minifix end distances (54, 72, and 90 mm) from the end of members were tested. Holes 15 mm in diameter and 14.5 mm in depth were drilled into the horizontal members for the minifix fastener housings. Connecting holes for the metal bolts 8 mm in diameter were drilled into the horizontal members. Holes 8 mm in diameter and 22 mm in depth were drilled into the horizontal members for the dowels. Corresponding holes (8 mm in diameter and 14 mm deep) were drilled into the vertical members for dowels. Holes (5 mm in diameter and 12 mm deep) were drilled into the vertical members for the threaded part of the metal bolts.

A total of 60 test specimens were prepared at three end distances (54, 72, and 90 mm), two different wooden dowel species (Beech and Oak), one loading format and 10 replicates from each

Table 1. Physical and mechanical properties of materials used in this study.

Materials	MC (%)	Average dry density (g/cm^3)	Air dry density (g/cm^3)	MOE (N/mm^2)	MOR (N/mm^2)	Shear strength (N/mm^2)
Oak	8.6	0.740	0.760	12,161.30	118.50	19.41
Beech	8.5	0.690	0.710	12,462.60	122.90	15.23
MDF-Lam	6.8	0.750	0.760	3465	26.02	5.54

MDF-Lam, medium-density fiberboard.

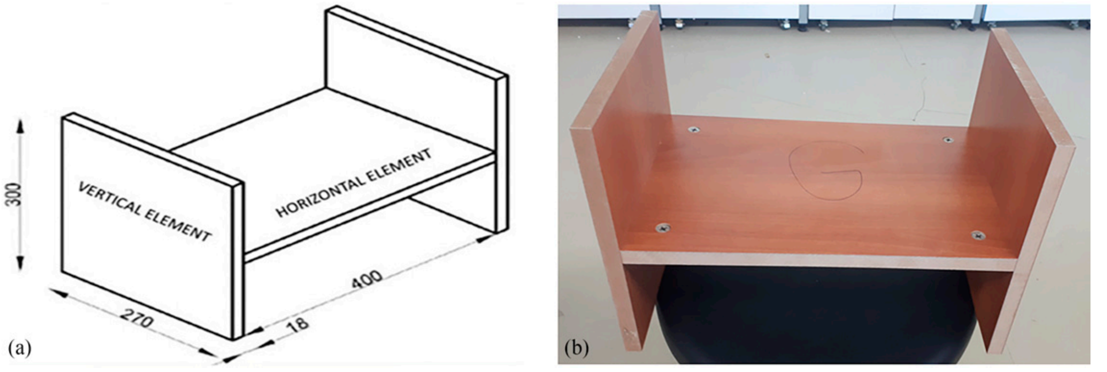

Figure 2. H-type joining test sample (a) and produce test sample (b) (dimensions in mm).

sample. Before the experiment, the samples were equilibrated at 20 ± 2°C and 65 ± 3% RH until they reached constant mass.

Method of Testing

The tests were carried out on a BMT E series universal testing machine, with a 10-kN capacity, in the mechanical testing laboratory at Usak University, Mechanical Engineering Department (Turkey). The test load was applied with a special arrangement prepared with a gap of 20 mm from the edges. The loading rate was 6 mm/min. Maximum loads read from the test machine were recorded in Newton's. There is no standard for the experimental setup, but some researchers have used similar strategies to determine the shear force capacities of both frame and box-type furniture assemblies with such arrangements (Deniz 2010; Kasal et al 2012; Yıldırım et al 2020). The shear force test set-up is shown in Fig 3.

Joint failure modes and maximum failure loads were recorded in Newton's (N). Shear force (*Fk*) corresponds to a joint for maximum (F_{max}) at failure modes where shear force (N) and F_{max} = max load at failure (N).

The shear force (F_k) was calculated by the following formula:

$$F_k = \frac{F_{max}}{2},$$

where F_k is the shear force (N) and F_{max} is the max load at failure (N).

Statistical Analyses

The data were analyzed using Minitab® 18 software (Minitab, Ltd., Coventry, UK). Analysis of variance (ANOVA) was performed to quantify the differences between variables at the 0.05 significance level for the individual data to examine the main factors (wooden dowel species and the

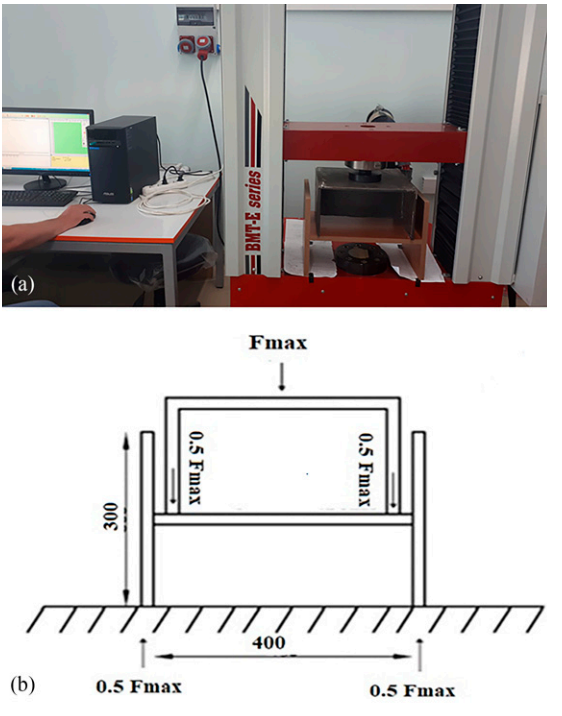

Figure 3. Universal test machine and testing device (a) and shear test points (b) (dimensions in mm).

Table 2. Descriptive statistical values of shear force capacity.

Wooden dowel species	End distances (mm)	Shear force (N)				
		X_{min}	$X_{ort.}$	X_{max}	SD	COV (%)
Oak	54	1536	1591	1630	26.1	1.64
	72	1506	1649	1712	56.1	3.41
	90	1489	1514	1563	25.2	1.66
Beech	54	1339	1454	1536	51.5	3.54
	72	1506	1567	1676	58.6	3.74
	90	1344	1405	1499	45.4	3.23

X_{min}, minimum; X_{max}, maximum; X_{ort}, mean; COV, coefficient of variation.

end distances from the end) and their interactions on the shear force capacity of H-type joints. Statistically significant differences were compared using Duncan's modified least significant difference test ($p < 0.05$).

RESULTS AND DISCUSSION

The mean, minimum, maximum, SD, and coefficient of variation (%) values of the shear force capacity of the H-type joints under load are given in Table 2. The ANOVA results for the shear force capacity values of the tested joints are given in Table 3.

Shear force capacities of joints with oak dowels and the minifix fastener (72-mm the end distance) were approximately 4% and 9% higher than for joints with end distances of 54 and 90 mm, respectively (Table 2).

When oak dowels were used, the shear force capacities of the joints with the minifix fastener (72-mm the end distance) were approximately 8%

Table 3. ANOVA of results for shear force capacity.

Source	DF	Adj. SS	Adj. MS	F-value	p-value
Wooden dowel species (A)	1	178,952	178,952	82.81	0.000*
End distances (B)	2	220,362	110,181	50.98	0.000*
A × B	2	7506	3753	1.79	0.177
Error	56	121,022	2161	—	—
Pure error	54	113,516	2102	—	—
Total	59	520,336	—	—	—

* p-value <0.05 is a significant difference.
SS: Sum of Square; MS: Mean of Square.
ANOVA, analysis of variance.

Table 4. Mean comparison results of shear force capacity for wooden dowel species.

Wooden dowel species	Shear force capacity (N)	HG
Oak	1585	A
Beech	1475	B

HG, homogeneous groups.

and 12% higher than for joints with end distances of 54 and 90 mm, respectively.

Mean shear force capacities for the wooden dowel species and the end distances for the minifix fastener in H-type furniture joints were highest (1649 N) in samples prepared with the end distance of 72 mm and an oak dowel, while the lowest value was obtained in the samples prepared with the end distances of 72 mm (1405 N) and beech dowels (Table 2).

Summary ANOVA results for the shear force capacity values of the tested joints are given in Table 3.

The effect of wooden dowel species and end distances on the shear force capacity of H-type furniture joints under shear load was statistically significant ($\alpha = 0.05$). The wooden dowel species and bilateral interactions were not statistically significant. When the calculated F values indicated that shear force capacity was most affected by the wooden dowel species, then the end distances from the end of minifix fastener, and the least from the interactions.

Comparisons between wooden dowel species indicated that the highest shear force capacity values were obtained for oak (1585 N) (Table 4). These indicated that the direct withdrawal force of single multigroove oak dowels was affected by the wood species of the joints, i.e. the shear bond strength between dowels and joint members was

Table 5. Comparison results of the shear force capacity for end distances the end.

End distances (mm)	Mean bending moment (N)	HG
72	1608	A
54	1523	B
90	1460	C

HG, homogeneous groups.

Figure 4. Types of deformation of H-type furniture joints resulting from the compression test: 54 mm end distance + oak dowel (a), 90 mm end distance + oak dowel (b), 72 mm end distance + oak dowel (c), 54 mm end distance + beech dowel (d), 72 mm end distance + beech dowel (e), and 90 mm end distance + beech dowel (f).

affected by the wood species of the joint members. The mean comparisons of bending moment capacity values of H-type furniture joints for the end distances are shown in Table 5.

The highest shear force capacity values were obtained with an end distance of 72 mm, and the lowest was with an end distance of 90 mm. The mean of shear force capacities of the end distance of 72 mm were 6% and 10% higher than in joints with the end distances of 54 and 90 mm, respectively. The maximum shear force capacity was reached at the end distance of 72 mm. When the end distance increased from 54 to 72 mm, shear force capacity increased while increasing end distance from 72 to 90 mm was associated with reduced shear force capacity.

Failure Modes

After testing, all experimental samples were visually inspected to identify the failure mode of the minifix fastener and dowels. There was no deformation in the connecting elements. The MDF-Lam was fractured due to the compression force on the fastener. Deformations were similar in all experimental specimens. Cracks formed toward the plate end around the minifix and dowel in all H-type furniture joints (Fig 4). As a result, the highest rates of deformation were in Beech dowels + an end distance of 90 mm test samples (see Fig 4[f]). Oak dowels + an end distance of 90 mm, oak dowel + an end distance of 72 mm, and beech dowels + an end distance of 54 mm samples followed, respectively (see Fig 4[a]-[e]).

CONCLUSIONS

This study presents the bending moment resistance of dowels of two wood species used in H-type furniture joints with minifix fasteners under shear load. The effect of end distance (54, 72, and 90 mm) was also considered. In general, the shear force capacity of H-type furniture joints with minifix fasteners under shear loads was significantly affected by dowel species, the end distances, and the interaction of these two factors. In particular, the tests showed the following:

1. Minifix fasteners with an end distance of 72 mm had the highest shear force capacity of the three end distances tested followed by 54 and 90 mm, respectively.
2. Oak dowels showed the best performance and beech had the lowest performance.
3. Minifix fasteners with an end distance of 72 mm along with oak dowels appeared to provide the best performance. The use of connectors with an end distance of 90 mm with beech dowels appears to be the least ideal.
4. The highest shear force capacity was obtained at an end distance of 72 mm in the samples with oak dowels. The lowest shear force capacity was obtained with a distance of 90 mm in samples with oak dowels.

As a result, an end distance of 72 mm from the edge of the joint combined with the oak dowel provided the best results in constructions requiring high shear force strength. The results of this study provided fundamental information on the strength properties of the selected minifix fastener as an RTA fastener, which will be useful for the disassembled furniture manufacturers and the engineering design of furniture constructions. However, further studies are recommended to examine other materials and combinations.

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