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Determination of Bending Moment of L-Type Corner Joints Used in Chair Production and Their Effects on Mechanical Performance of Chairs

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Abstract: The objective of the study was to determine the mechanical performance of L-type joints and chairs produced using mortise-tenon and dowel-joint techniques by diagonal compression tests and diagonal tensile tests. Two types of corner-joints were prepared from beech wood at the laboratory, which was mortise-tenon and dowel joints. Two grooved dowels were used in the dowel joints. The corner-joint samples were subjected to diagonal compression and tensile tests at the universal testing machine. The chairs were produced from these corner-joints, and their mechanical performance tested using furniture test equipment in accordance with EN 1728 standard. The mortise-tenon joint in the diagonal tensile testing had the highest bending moment with an average value of 673.28 Nm while the dowel-joint had the lowest bending moment in the diagonal compression testing with an average value of 75.36 Nm. A load-bearing capacity of 673.28 Nm was obtained from diagonal tensile testing, and 95.54 Nm was obtained from the diagonal compression test. All the chairs produced from mortise-tenon or dowel-joint did not show any failure at the corner-joint area. The chairs produced with a mortise-tenon joint had a better mechanical performance as the corner-joints test results were considered. The mortise-tenon joint showed better mechanical performance than the dowel-joint technique. The load-bearing capacities obtained from the diagonal tensile testing were found to be higher than those obtained from the diagonal compression test. The chairs produced from mortise-tenon or dowel-joint did not show any failure at the corner-joint area after the test specified in EN 1728 standard.

Keywords: Corner joint; mortise-tenon joint; dowel-joint; mechanical performance; chair.

1. Introduction

Furniture can be characterized as an aesthetic and functional consumption product. Furniture designs are expected to meet the functional purposes loaded, as well as satisfy the aesthetic demands of users. In addition, furniture should be economical in terms of material and production

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requirements. The furniture should be designed to be easy and practical to manufacture, to provide a technically reliable service for users from economical materials suitable for design purposes [1]. Mortise and tenon joints are still widely used in wooden constructions. Despite the increasing use of dowel joints, mortise, and tenon joints are irreplaceable for some types of furniture construction [2]. The dowel joint is employed in numerous, diverse applications in furniture structure, including structural reinforcements in cabinet making and for furniture shelf supports [3]. Dowel joints are the most frequent alternative to mortise-tenon joints due to their significant advantages to the furniture manufacturers' easy and fast production process, less energy, and waste [4].

Chairs are exposed to different loads directly or indirectly during their lifetime. Generally, different types of mechanical loading such as tension, compression, bending, shear, and torsion affect chair combinations. As a result of these loads, the negative effects such as bending, cracking, and fracture can be observed in chairs [5]. Burdurlu et al. [6] investigated the effects of corner chock and joint type on bending resistance in rail to leg joints. For this purpose, they have chosen mortis-tenon and dowel joint types due to their frequent use in the application, and as a result, they explained that the highest bending resistance is obtained by dowel joint method. Eckelman et al. [7] investigated the bending moment capacity in round-groove dowel joints with and without tenon diameters in which the pins reduce torque and increase the tightness of the joint. Eckelman et al. [8] investigated the effect of cross pinning the tenons of round mortise and tenon joints on the bending moment capacity of the joints. They concluded that cross-pins substantially reduce the bending moment capacity of round mortise and tenon joints. Placement of the cross-pin away from the root of the tenon reduces the loss in bending moment capacity. Tensile testing strength of T-type furniture joints made of different wood materials by applying various connection techniques was compared by Efe et al. [9]. They reported that the highest bending moment capacity was obtained from the mortise-tenon joint while the lowest bending moment capacity was given by mini fix plus dowel joints. Eckelman and Haviarova [10] investigated the performance tests of round mortise - tenon joint school chair constructions. They reported that the strength and resistance of pinned but unglued mortise-tenon joints were approximately the same as glue mortise-tenon joints.

It is inevitable that the dimensions of the corner joint will have a significant impact on the mechanical properties of the chairs. In this study, the effect of corner joint type on the diagonal tensile testing and diagonal bending strength was investigated.

2. Materials and Methods

2.1. Wood material and adhesive.

10 mm thick oriental beech lumbers (*Fagus orientalis Lipsky*) without any defect were used to produce corner joints. The kiln-dried lumbers (12% moisture content) were supplied from a local timber market. The lumbers were conditioned at 20 °C and 65% relative humidity until constant weight. The commercial type polyvinyl acetate (PVA) adhesive was used as a binder in this study.

2.2. Preparation of corner-joint specimens.

Two types of corner-joints were prepared from beech wood at the carpenter shop, which was mortise-tenon and dowel joints. Two grooved dowels were used in the dowel joints. The dowels used in the preparation of the corner joints were prepared with a diameter of 10 mm and a length of 35 mm. 2 dowel spacers were placed at 32 mm in joining them. In the preparation of mortis-tenon joint specimens, a mortises with dimensions of 10 mm thick, 40 mm wide, and 23 mm long were made at the carpenter shop. The lengths and thickness of the corner joints in the finished state were 250 x 250 mm and 20 mm, respectively. A total of 80 test samples were prepared for two type corner joints, 20 samples for the diagonal compression testing, and diagonal tensile testing of each type of joint. The samples of mortise-tenon and dowel-type joints are shown from Figures 1 to 4. The corner-joint samples were subjected to the diagonal compression and tensile tests at the universal testing machine (Figs. 5 and 6). In the diagonal tensile testing, wheeled metal plates were placed at the places where the horizontal and vertical parts came into contact, both to allow the parts to move freely and to prevent friction. The tests were carried out on a universal testing machine (Lloyd Instruments, USA) with a load capacity of 100 kN and 1.5 mm/min speed at 20 °C temperature. The loads applied to the test specimens were continued until the maximum failure load occurred.

The bending moment in the tensile testing was calculated according to the below formula:

$Mc = (Fc/2) \times Lc$

Where;

Mc= Bending moment in tensile testing (Nm)

Fc = Maximum failure load in tensile testing (N)

Lc = moment arm in tensile testing (m)

The bending moment in the compression testing was calculated according to the below formula:

$Mb = Fb \times Lb$

Where;

Mb= Bending moment in compression testing (Nm)

Fb = Maximum failure load in compression testing (N)

Lb = Moment arm in compression testing (m).

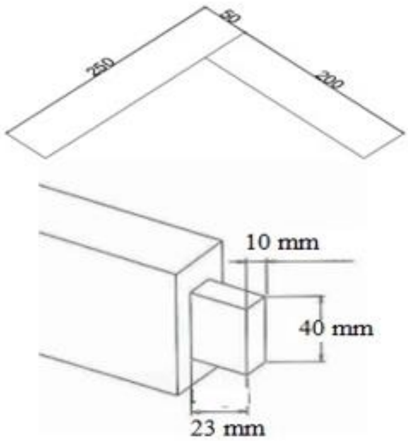

Figure 1. The size of the tenon.

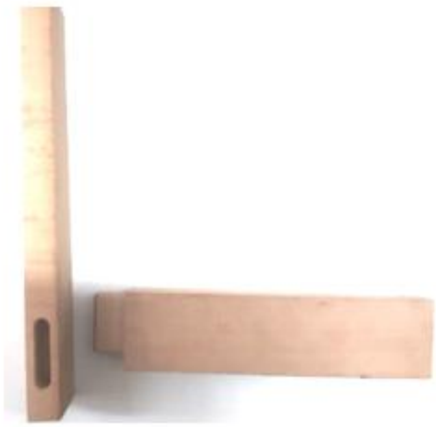

Figure 2. Rectangular end mortise.

Figure 3. Round dowel joint sample.

Figure 4. Prepared corner-joint specimens.

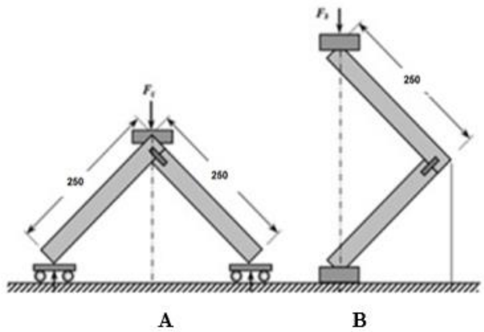

Figure 5. Schematic of corner-joint test specimens in diagonal tensile testing (A) and diagonal compression testing. (B).

A B

Figure 6. Corner-joint tests using a universal test machine. A: Compression test. B: Tensile test.

2.3. The preparation of the experimental chairs using the corner-joints.

The chairs used in the experiments were produced from beech timbers having an average moisture content lower than 12%. A total of 20 samples were produced for a ready type of chair assembly in a commercial chair company, Inegol, Bursa. In the production of chairs, the joining points were glued with PVA glue and then compressed using clamp and allowed to dry. The seat of the chair was prepared by a 5 mm thick medium-density fibreboard (MDF) (Fig. 7).

Figure 7. A photo of the chair produced.

The dimensions of the chairs produced are given in Table 1.

Table 1. The dimensions of the chairs produced.

Dimension of the chair	The value
The chair height	900 mm
Height of back side	410 mm
Height of frontside	430 mm
Width of fronside	460 mm
Upperside width	400 mm
Deepness	480 mm

2.4. Determination of mechanical performance of the chairs.

The mechanical performance of the chairs was carried out in accordance with European Standard (EN) 1728 standard [11] (Fig. 8). The seat part of the chair was loaded to provide 750 N weight, rear feet were supported with wedges, and 300 N force was applied to the upper part of the backrest. The applied force was maintained for 2±1 s, and the test was continued with 25000 repetitions as specified in EN 12520 standard [12]. After the test completed, the chairs were checked for any failure at the corner-joint. If there is no failure problem at the corner joints of the chair, the specimens pass the tests successfully.

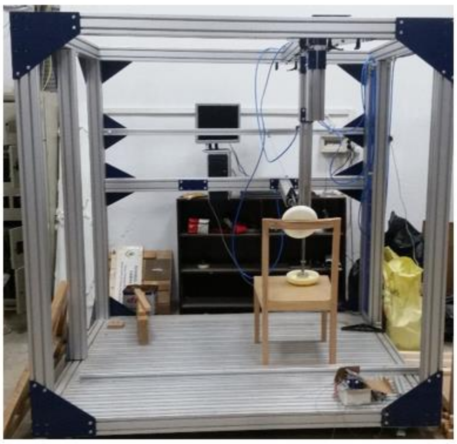

Figure 8. Chair testing machine.

2.5. Statistical Analysis.

The results of the corner-joint test and chair-joint test were computed and compared with each other by using ANOVA and T-test statistical analysis.

3. Results and Discussion

3.1. Mechanical performance of corner-joint.

The mortise-tenon joint in the diagonal tensile testing had the highest bending moment with an average value of 673.28 Nm while the dowel-joint had the lowest bending moment in the diagonal compression testing with an average value of 75.36 Nm. Load-bearing capacity of 673.28 Nm was obtained from the diagonal tensile testing, and 95.54 Nm was obtained from the diagonal compression test. When the *T*-test results given in Table 2 were examined, a significant difference was found between the diagonal compression and diagonal tensile tests at 95% confidence level in mortise-tenon joints. The load-bearing capacities obtained from the diagonal tensile testing were found to be higher than those obtained from the diagonal compression test. As for the dowel-joint tests, the average of 361.02 Nm in the diagonal tensile testing and 75.36 Nm in the diagonal compression testing were obtained. According to the *T*-test results of dowel- joints, a significant difference was found in the diagonal compression and diagonal tensile testing at the 95% confidence level. The diagonal tensile testing values were about 5 times higher than the diagonal compression testing values.

As the diagonal compression test data were examined, the load-bearing capacity of mortise-tenon specimens was higher than the dowel joint specimens. A significant difference was found in the 95% confidence level in the *T*-test results. The loadcarrying capacity of mortise-tenon specimens was 20.18 Nm higher than that of the dowel-joint specimens. In the mortise-tenon joining technique, the bonded surface area of the joined elements was higher than that of the dowel-joint specimens. Thus, it can be explained why the mortise-tenon jointing technique was found to be more successful in the diagonal compression testing. Similar results were observed in previous studied [6,9,13]. For example, Imirzi et al. [13] investigated the strength, stiffness, and modulus of the elasticity of dowel, mortise, and loose-tenon, and mortise and tenon L-type furniture joints under diagonal tension and compression loads. They reported that the highest stiffness/strength values were estimated in the mortise and tenon joints constructed of white oak, whereas the dowel joints constructed from Turkish beech showed the lowest stiffness/strength and deformability.

In the diagonal tensile testing, the bending moments of the joints were found to be 673.28 Nm for mortise-tenon samples and 361.02 Nm for the dowel-joint samples. When the group averages were compared with each other, a significant difference was found in the 95% confidence level according to *T*-test results. The mortise-tenon samples showed better mechanical performance in the diagonal tensile testing.

As shown in Table 2, the lowest mechanical performance in the corner-joint tests was found in the dowel joint specimens (75.36 Nm) in the diagonal compression testing, while the highest mechanical performance was found in the mortise-tenon specimens (673.28 Nm) in the diagonal tensile testing. The statistical comparison of the averages of the mortise-tenon samples in diagonal compression testing and tensile testing at a 95% confidence level is given in Table 4. It was found a significant difference between the groups. In a previous study, Eckelman [14] reported that mortise and tenon joints were approximately 40% stronger than dowel joints assembled with 2 dowels, with the same rail widths, and with the tenon width the same as the dowel spacing.

3.2. Mechanical performance of chairs.

The seat part of the chair was loaded to provide 750 N weight, rear feet were supported with wedges, and 300 N force was applied to the upper part of the backrest. The applied force was maintained for 2±1 s. The test was continued with 25000 repetitions. It was not observed any failure in the corner joints of the chair after the test was completed. Based on the detailed observation on the corner-joints, all the chairs produced from the mortise-tenon or dowel-joint did not show any failure at the corner-joint area. The results showed that both joint types passed the EN 1728 standard. It was expected that the chairs produced with the mortise-tenon joint had better mechanical performance than the chairs produced with the corner-joints based on the results of corner joints given in Table 2.

Table 2. The bending and tensile moments of the corner-joint test specimens in compression and tensile.

Corner-joint type	Average (Nm)	Specimen number (Nm)	Standard deviation (Nm)	Variance	Minimum (Nm)	Maximum (Nm)
Dowel joint (Diagonal compression testing)	75.36 a*	20	6.37	40.59	58.78	84.19
Dowel joint (Diagonal tensile)	361.02 b	20	25.51	650.75	322.61	405.22
Mortise-tenon joint (Diagonal compression testing)	95.54 c	20	13.57	184.29	66.00	117.21
Mortise-tenon joint (Diagonal tensile)	673.28 d	20	46.81	2191.20	608.96	738.70

* Groups with same letters in column indicate that there is no statistical difference ($p<0.05$) between the specimens according to *T*-test.

4. Conclusions

The results of the present study revealed that the mechanical performance of the corner-joints was significantly affected by the joint type. According to the test results, the corner joint prepared using the mortise-tenon technique gave higher results than that of the dowel-joint technique in the tensile and compression tests. As for the chair tests, the chairs showed good performance at the loan amount and number of repetitions specified in the EN 1728 standard. No deflection or crack was observed in the corner-joint of the chairs after the test cycles were completed. Based on the corner-joint tests, the mortise-tenon joint type was suggested for the chair manufacturers.

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Conflicts of Interest

The authors declare no conflict of interest.

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