WOOD RESEARCH
54 (3): 2009
79-88

THE BENDING MOMENT CAPACITIES OF MITRE FRAME CORNER JOINTS WITH DOVETAIL FITTINGS

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ABSTRACT

In this study, the bending moment capacities under the diagonal compression and tensile loadings of the mitre frame corner joints with dovetail fittings were investigated. Solid poplar wood (*Populus nigra*) was used in the production of framework pieces. Recently, mitre frame corner joints with dovetail fitting are preferred in practice. This has been influential in the making of this study. A total of 80 each mitre frame corner joint specimens with dovetail fitting were prepared for this purpose. Of these, 20 were prepared with polyvinyl acetate (PVAC) adhesive, 20 were prepared with polyurethane (PU) adhesive, 20 were prepared with cyanoacrylate (CA) adhesive and 20 were prepared without adhesive (WA). Solid poplar wood (*Populus nigra*) was used as a frame material. The specimens were subjected to diagonal tensile and compression processes in the universal test machine in accordance with ASTM-D 143-94. The data obtained at the end of the tests were analyzed statistically and the results were evaluated. According to this, the highest bending moment capacity under the diagonal compression loading (MC-L) (55.71 N · m) and bending moment capacity under the diagonal tensile loading (MC-T) (160.55 N · m) was obtained in the specimens bonded with PVAC adhesive. Whereas, the lowest MC-L (18.45 N · m) and MC-T (14.06 N · m) was obtained in the specimens without adhesive (WA). The difference between the MC-T and the MC-Cof the specimens bonded with the CA and PU adhesives was insignificant. Accordingly, it is definitely necessary to use adhesives in the bonding of dovetail fittings for obtaining a higher MC-T and MC-C. The best result among the available adhesives was obtained with the PVAC adhesive.

KEY WORDS : adhesives for wood; tensile strengths; compression strengths; mitre frame corner joints.

INTRODUCTION

Frame construction is a form of construction used in cabinetmaking and other furnishing elements for doors, windows, sides and fronts of cabinets. The frame appearance, just as it can be in basic geometric forms, such as a square, rectangle, oval and circle, it can also be in curved forms as a combination of these with free external lines. Any frame construction is composed of two main elements, the frame and the frame opening elements. The frame requires four or more pieces: two pieces for the vertical stiles and two pieces for the horizontal rails. If an intermediate horizontal divider is used, then this is called a cross rail or lock rail. An intermediate vertical divider called a cross stile or mullion may also be used (Feirer and Chas 1970). These vertical and horizontal pieces in wooden frames can be produced with solid wood or as panel construction from particleboards, fiberboards, veneer core plywoods or lumber core plywoods. These parts, depending on the number of frame openings, are joined to each other at the corners and intermediate parts of the frame. The openings between the frame pieces are inserted with glass in products where display and visual quality are sought and with panels of different construction in products aimed at storage without having a purpose of display.

In the frames, vertical, horizontal or diagonal loads occur at the joining points connected to the total weight of the frame and temporary loads. It is necessary for the strength of the frame to be adequate in order to withstand the emerging forces. Otherwise, gaps at the joining places could occur initially and subsequently disintegration could occur in the pieces. The strength of the frame is connected to the materials used in the construction of the frame pieces, the type of joint attaching these pieces to each other, the type of adhesive used in the joints and the panel receiving type at the inside edges of the frame pieces (Eckelman 1971, Hill and Eckelman 1973, Englesson 1973, Molain and Carroll 1990, Zahn 1991, Zhang and Eckelman 1993, Efe 1994, Özçiftçi1995, Eckelman and Lin 1997, Örs and Efe 1998, Kasal 1998, 2004, Kharaouf et al. 1999, Kap 1999, Imirzi 2000, Falk et al. 2001, Efe and Imirzi 2001, Örs et al. 2001, Hwang and Komatsu 2002, Yadam et al. 2002, Sawata and Yasamura 2002, Erdil et al. 2003, Kurt 2003).

Frame parts in a frame construction are joined to each other at the corners and intermediate parts of the frame with dowels, mortise and tenon, spline, and profiled joints or special fitting elements such as plastic dovetail fittings. The joints can be made with or without adhesive according to the objective and type of joint. Plastic dovetail fitting has a suitable form of joining in mass production due to the fact that opposite holes can be easily opened technologically and the elimination of the necessity of remaining in a pressed position until the adhesive layers become hard after joining. For this reason, the use of dovetail fitting elements is gradually becoming more widespread, especially in the corner, intermediate and cross joints of frame constructions. The material of the frame pieces, the number of dovetail fitting elements, the position of the joint location and the type of adhesive used are influential on the strength of these joints. In the literature search made, no study related to this joint type was encountered, despite the fact that it is the most widely used joint type in the frame construction at present. This has been the starting point of this research. In the study, it has been aimed to determine the bending moment capacities under the diagonal tensile and compression loadings of joints in case solid poplar wood is used as the material in frame pieces and one each dovetail fitting is placed right at the center of the joining line and different adhesives are used for fixing the frame pieces.

MATERIAL AND METHODS

Poplar wood is gradually becoming even more preferable as material in the production of solid wooden frames. The fact that poplar is inexpensive, can be grown in a short period of time, has a low density, has sufficient strength despite its low density and that it is suitable for surface finishings, such as painting and varnishing, play an important role in this preference. Poplar wood has been used in the production of framework pieces due to these characteristics and because it is suitable in practice.

Poplar wood (*Populus nigra*) from which the specimens to be used in the study were supplied from the Beytepe/Ankara region of Turkey by felling and bucking them according to the ISO 4471 standards. Care was taken in felling that the trunk and crown formation of the trees were normal and strong, that the colors were normal, that there were no cross grains on the trunks, and that they had not been attacked by insects and fungus. Some properties of poplar trees used in the study are given in Tab. 1.

Tab. 1: Some characteristics of the poplar woods used in the study

POPLAR			
Tree No	**Height (m)**	**Diameter at 1.30 m(cm)**	**Age**
1	**20**	**50**	**20**
2	**20.5**	**45**	**20**
3	**20**	**44**	**20**
4	**18**	**35**	**20**
5	**23**	**50**	**20**
Air dry specific gravity ($g.cm^{-3}$)			**0.4045**
Oven-dry specific gravity ($g.cm^{-3}$)			**0.3890**

Plastic Dovetail Fittings and Frame Parts: Dovetail fittings are produced from PVC plastic in various colors and different dimensions. A suitable color is selected for the surface of the frame. The sides are grooved in order to increase friction. The plastic dovetail fittings used in the study and its dimensions are given in Fig. 1a.

The dimensions of the sample frame parts used in the test and the positional dimensions related to the placement of the dovetail hole are given in Fig. 1b.

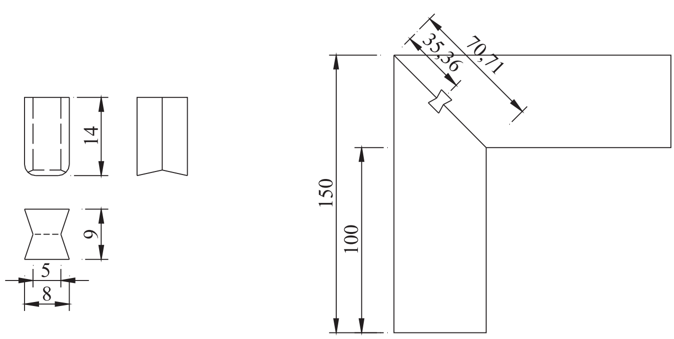

Fig. 1: (a) Plastic dovetail fitting (dimensions are in mm)
(b) Position of the test pieces and the plastic dovetail fitting

Polyvinylacetate (PVAC) adhesive: The dispersion, which has polyvinylacetate as its basic substance, is an adhesive that contains a solid substance amount of 55% that has a viscosity of 12-18 Pa.s. at a temperature of 20°C and that has a density of 1080 kg.m^{-3}. It was used in accordance with the manufacturer's recommendations.

Polyurethane (PU) Adhesive: It is a single-component adhesive having a 100% solid substance amount, a density of 1200 kg.m^{-3}and a viscosity of 4-5 Pa.s. at a temperature of 20°C. It was used in accordance with the manufacturer's recommendations.

Cyanoacrylate (CA) Adhesive: It is a type of adhesive with a double component based on cyanoacrylate and amine. Its density is 1060 kg.m^{-3}, its solid substance amount is 100% and its viscosity is 1.5 Pa.s. The components are applied separately to the surfaces to be glued. It is sufficient to hold the parts together for up to 10 seconds after joining them. Complete hardening materializes in 24 hours. It was used in accordance with the manufacturer's recommendations.

It was envisaged to prepare a total of 80 each specimens [1 (material type) x 4 (adhesive types) x 2 (strength type) x 10 (number of tests repeated) = 80] for the determination of the MC-T and MC-C of the frame corner joints with dovetail fittings with three different types of adhesive (PVAC, PU and CA) and without adhesive on the poplar solid wood frames.

The logs obtained in the supplying region were brought to the research location. From these logs, the stocks (lumber) of specimens were cut in the rough measurements so that the annual rings would come with a maximum perpendicularity to the surface, by also taking into account the dimensions of the specimen and the tolerances that would emerge with drying. These stocks were subjected to kiln drying until they reached a 12% moisture content value.

A total of 80 each pieces with the dimensions of 150 x 50 x 18 mm were obtained from the stocks after drying. These pieces were mitred in one corner in a manner to produce a frame corner of 150 x 150 mm as shown in Fig. 1. A dovetail hole was opened on these pieces for the dovetail fittings in a manner so that it would be at the exact center of the right angle sides. From these pieces, the experimental pieces were formed of 20 each without adhesive, 20 each bonded with PVAC adhesive, 20 each bonded with PU adhesive and 20 each bonded with CA adhesive. Immediately after coating adhesives on the joining places for the bonded pieces, the dovetail fittings was hammered and the frame corner test specimens obtained were left to dry. The unbonded specimens were joined only by hammering the dovetail fittings. Subsequently, the specimens were kept in a climatization chamber at a temperature of 20+2°C and a relative humidity of 65+5% until they reached an unchanging weight (until 12% moisture content). The general principles given in ASTM-D 143-94 were complied with in the preparation of the specimens.

The 80 specimens were subjected to the diagonal compression and tensile loadings in the 1-ton universal test machine in accordance with ASTM-D 143-94. The specimens were connected to the machine with special apparatuses in conformance with the standards and a loading suitable to the models given in Fig. 2 was applied. The loading speed of the machine throughout the tests was adjusted to 5 mm.min^{-1}. The loading continued until there was a separation or breaking at the joining places of the specimens and the load (F_{max}) at this instant was determined and recorded. Subsequently, the MC-T and MC-C were calculated with these values.

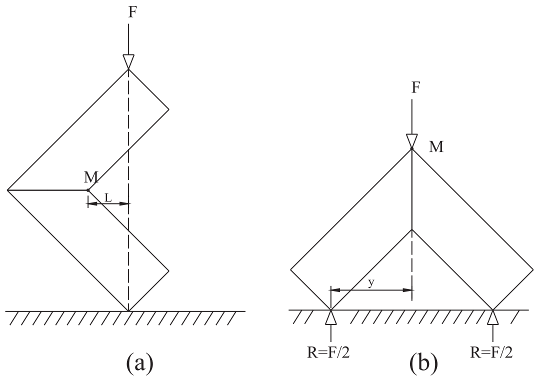

Fig. 2: Test system diagram of diagonal compression (a) and tensile (b) loadings (R=reaction forces)

The formulas given below were used in the determination of the MC-C of the specimens:

$$M_{dc} = F_{max} x\ L\ (N \cdot m) \tag{1}$$

Here; M_{dc}: MC-C (N · m), Fmax: force at the moment of separation or breaking (N), and (L): moment arm (0.0353 m)

The MC-T of the specimens were calculated with the equation given below:

$$M_{dt} = F_{max}/2\ x\ y\ (N \cdot m) \tag{2}$$

Here; M_{dt}: MC-T (N · m), Fmax: force at the moment of separation or breaking (N), and y: moment arm (0.0707 m)

The F test was used in the determination of the effect of variables on the bending moment capacity. In case the difference between the groups was significant, then a comparison was made with the Duncan's Multiple Range Test. The SPPS 11.5 package program was used in the calculations of the arithmetic mean, the standard deviation, the minimum and the maximum values.

RESULTS AND DISCUSSION

The bending moment capacity values obtained from the specimens with dovetail fittings attached with different adhesive types and without adhesive (WA) at the end of the tests are given in Tab. 2.

As it can be seen from the table, the highest MC-C (55.71 N · m) was obtained in the specimens bonded with PVAC adhesive and this is followed at 39.87 N · m in the specimens bonded with PU adhesive. The MC-C of the mitre corner joints with dovetail fittings in which adhesive was not used was 18.45 N · m and this was the lowest diagonal compression loading value.

The highest MC-T (160.55 N · m) was obtained in the specimens bonded with PVAC adhesive. This was followed by the specimens bonded with CA and PU adhesives. The lowest MC-T (14.06 N · m) was obtained in the unbonded specimens.

The F test was used at the end of the tests for the analysis of whether or not there was a significant difference in the MC-T and MC-C of the specimens (Tab. 3).

Tab. 2: The bending moment capacities under the diagonal tensile and compression loadings of the mitre frame corner joints with dovetail fittings according to the type of adhesive

The bending moment capacity under the diagonal compression loading (N · m)					
Adhesives	N	Mean	Std.Deviation	Minimum Value	Maximum Value
WA	10	18.45	1.29	12.02	24.75
PU	10	39.87	3.69	25.45	65.05
PVAC	10	55.71	5.85	36.76	94.74
CA	10	38.67	4.13	21.21	61.51
The bending moment capacity under the diagonal tensile loading (N · m)					
Adhesives	N	Mean	Std.Deviation	Minimum Value	Maximum Value
WA	10	14.06	0.54	10.61	16.26
PU	10	43.26	3.05	33.23	65.75
PVAC	10	160.55	16.38	97.57	221.29
CA	10	57.69	4.81	36.76	80.60

WA: Without adhesive PU: Polyurethane PVAC: Polyvinyl acetate CA: Cyanoacrylate

Tab. 3: The analysis of variance related to the effect of the adhesive type on the bending moment capacities under the diagonal tensile and compression loadings in the mitre frame corner joints with dovetail fittings

The bending moment capacity under the diagonal compression loading					
	Sum of Squares	Degree of Fredom	Mean Square	F	P
Between Groups	6996.38	3	2332.12	13.98	0.000
Within Groups	6003.68	36	166.76		
Total	13000.07	39			
The bending moment capacity under the diagonal tensile loading					
	Sum of Squares	Degree of Fredom	Mean Square	F	P
Between Groups	121905.22	3	40635.075	53.947	0.000
Within Groups	27116.70	36	753.242		
Total	149021.93				

Tab. 4: The homogeneity groups of the bending moment capacities under the diagonal compression and tensile loadings according to the types of adhesive

Adhesives	N	Homogeneous Subsets (α= 0.05)		
		1	2	3
The bending moment capacity under the diagonal compression loading				
WA	10	18.45		
CA	10		38.67	
PU	10		39.87	
PVAC	10			55.71
The bending moment capacity under the diagonal tensile loading				
WA	10	14.06		
PU	10		43.26	
CA	10		57.69	
PVAC	10			160.55

According to this, it was determined that there was a significant difference among the MC-T and MC-C occurring according to the adhesive combinations in $\alpha = 0.05$ significance and 95% reliability level and that this difference was significant ($p<0.05$) (Tab. 3).

The Duncan's Multiple Range Test was applied to determine among which groups there was a difference and the homogeneity groups emerging at the end of the test are given in Tab. 4.

As it can be seen from the table, the highest values from the aspect of both the MC-T and MC-C are obtained in joints with the PVAC adhesive. Whereas, the lowest values are obtained in the joints without adhesives (WA). Since the PU and CA adhesives fall into the same homogeneity group for both types of strengths, the difference in the strength values obtained with these two types of adhesives is insignificant. Since the MC-T and MC-C of the joints without adhesive are the lowest among the existing alternatives, using adhesive together with the dovetail fitting increases the MC-T and MC-C of the joints. Since the highest values are obtained in the joints with PVAC, the PVAC adhesive together with the dovetail fittings should be preferred in the joints for obtaining higher MC-T and MC-C Since the difference between the MC-T and MC-C obtained with the CA and PU adhesives is insignificant, any one of these two adhesives could be preferred as an alternative to the PVAC adhesive

CONCLUSION

In this study, the effect of the type of adhesive on the the MC-T and MC-C of the joints was studied when the dovetail fittings are used in the corners of the frames made from solid poplar.

Since the MC-T and MC-C of the joints of the dovetail fittings without adhesive were smaller than the joints with all of the other adhesives, adhesives should definitely be used in these types of joints to increase strength.

Among the three adhesive types, PVAC, PU and CA, the highest bending moment capacity was obtained with the PVAC adhesive. It was followed by the CA and PU adhesives. Since the differences between the MC-T and MC-C values provided by these two types of adhesives are statistically insignificant, either one could be preferred.

Due to its structure, the PVAC adhesive can penetrate deeper into the wooden material compared to the other two types of adhesive. A stronger bond and layer is formed between the two materials, which are bonded with the adhesive penetrating deeper (inside the cell cavities) into the material. Furthermore, the PVAC adhesive has a flexible bond structure. It is thought that higher MC-Ts and MC-Cs are obtained in the joints with the dovetail fittings with PVAC adhesive because of these two characteristics.

As it was stated in the introduction, there are some studies related to the corner and intermediate joints with dowels and mortise and tenon in frame constructions. However, a comparison among the studies could not be made since conformity could not be provided between the materials and details used in these joints with the details of this study. It is planned to conduct new studies on this subject.

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