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# EFFECT OF ADHESIVE TYPE ON THE BENDING MOMENT CAPACITY OF MITER FRAME CORNER JOINTS

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The bending moment capacity was studied under the diagonal tensile and compression loadings of miter corner joints with dovetail fitting in frames made with medium density fiberboard (MDF). The influence of the type of adhesive in the joints with dovetail fitting on bending moment capacity under diagonal tensile and compression loading were considered, and the joints without adhesive were compared. A total of 80 each miter frame corner joint specimens with dovetail fitting were made. Polyvinyl acetate (PVAc), polyurethane (PU), and cyanoacrylate (CA) adhesives were used, and 20 specimens were prepared without adhesive (WA) with dovetail fitting. MDF was used as a frame material, as in normal practice. The specimens were subjected to diagonal tensile and compression loadings in accordance with ASTM-D 143-94. The data were analyzed statistically. The highest bending moment capacity under diagonal tensile loading (46.09 Nm) was obtained in the specimens bonded with CA adhesive and the highest bending moment capacity under diagonal compression loading (72.04 Nm) was obtained in the specimens glued with PVAc adhesive. Other than this, since there is no difference between these and the unbonded joints, the PU adhesive was not effective in increasing the bending moment capacity under diagonal tensile loading, and the PU and CA adhesives were not effective in increasing the bending moment capacity under diagonal compression loadings.

## INTRODUCTION

Frame construction is used in cabinetmaking and other furnishing elements for doors, windows, sides, and fronts of cabinets. The frame appearance can be in basic geometric forms, such as a square, rectangle, oval and circle, and 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, this is called a cross rail or lock rail. An intermediate vertical divider called a cross stile or mullion may also be used (Feirer 1988). 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 with dowels, mortise and tenon, spline, and profiled joints or special fitting elements. The joints can be made with or without adhesive according to the objective and type of joint. The openings between the frame pieces are inserted with glass in products where display and visuality 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 dependent on the materials used in the construction of the frame pieces, the type of joining of 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 (Özçifçi 1995; Kap 1999; Kasal 2004).

Studies of the strength of furniture joints have mainly focused on two types of joints; mortise and tenon joints and dowel joints. Eckelman (1971), Zhang and Eckelman (1993), Zhang et al. (2002), Hwang and Komatsu 2002, Sawata and Yasumura (2002), Eckelman and Haviarova (2007), and Altınok et al. (2009) have studied the strength of dowel joints according to diameter and length of dowels, number of dowels, adhesives used, and joint tolerances. Hiil and Eckelman (1973), Smardzewski (2002), Eckelman et al. (2004), Tankut and Tankut (2004), Erdil et al. (2005), Eckelman et al. (2006) and Tankut (2007) investigated the effects of joint dimensions, joint shape (round or rectangular tenons, shoulders), adhesive type, bond line thickness, and joint tolerances on the strength of mortise and tenon joints in the skeleton type of furniture construction. Efe and Imirzi (2001) and Efe et al. (2005) compared the dowel, mortise and tenon, minifix, and bolted joints in construction of solid wood skeleton furniture. Some researchers focused on the joints in case-type furniture. Eckelman and Lin (1997) evaluated the bending strength of case-type furniture corner joints constructed with injection-molded spline. Vassiliou and Barboutis (2008) evaluated the strength of middle and corner furniture joints constructed with wood and plastic biscuits in particleboard and MDF. Atar et al. (2009) carried out a study to determine the performance of different wood biscuits on the diagonal compression and tension strength for case-type furniture corner joints. Also Tankut and Tankut (2009) studied on the effects of fastener, glue, and composite material types on the strength of corner joints in case-type furniture construction. Atar et al. (2010) carried out separate research on corner box-type joints. Other than these studies, some studies were carried on bolted connections in wood and wood composites (Molain and Carrol 1990; Zahn 1991; Kharaouf et al. 1999; Örs et al. 2001; Erdil et al. 2003).

In practice, the usage of intermediate products whose surfaces are covered with natural or plastic veneers in the production of wood products is gradually becoming more widespread. Plastic veneer-covered intermediate products are preferred more due to the

fact that surface finishing processes are not needed in these applications. The particleboard and fiberboard types covered with polyvinyl chloride (PVC), melamine, plastic laminates, or paint are within this scope. It is possible to reach higher production capacities with less investment by using these types of boards in production due to the elimination of the veneering and surface finishing processes. Based on this logic, profiles have been developed for frame pieces to facilitate the production process in frame constructions.

In general, medium density fiberboards (MDF) are used in the production of these profiles. First of all, profiles are processed on the surface and edges of the frame pieces by taking into consideration aesthetic differentiation and the receiving form of the frame panels. After this stage, the pieces are wrapped with surface veneers (melamine, PVC, etc.) on four sides at the same time. Profile wrapping machines are used for this purpose. The frame profiles, which are standardized, are presented in the form of packages for the preference of the frame producers.

Frame profiles procured from the market for any frame production are subjected to size measuring for butt or miter joints according to the frame dimensions, and they are prepared to be ready for installation by opening holes for fitting elements. Plastic dovetail fittings and adhesive are used in the assembly of the frame parts to each other.

Leaving economics aside, two technical aspects are taken into consideration in choosing an adhesive: one deals with bond performance and the other deals with bond formation. With respect to bond performance, resistance to four degradative factors provides a means of rating adhesives on the basis of durability: stress, heat, moisture, and organisms, identified by the acronym SHMO. The factors that are most likely to subvert bond formation include gaps, pressure, moisture content, temperature, assembly time, catalyst addition, mixing, and pot age. These factors are the handling properties of the adhesives that make the adhesive fit the operating circumstances with a minimum risk of misuse and failure, i.e., tolerance to the specifics of the process (Marra 1992).

Dovetail is a suitable form of joining in mass production due to the fact that opposite holes can be easily opened technologically, and this approach eliminates the necessity of holding the pieces 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, just as in practice, it has been aimed to determine the bending moment capacity under diagonal tensile and compression loadings of joints in case MDF 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.

## EXPERIMENTAL

## Materials

*Plastic dovetail fitting and frame parts*

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

MDF with a thickness of 18 mm and density of 767 kg/m$^3$ was used in the frame pieces. The fact that MDF is used in the ready-made frame profiles contributes to the preference of this material. The dimensions of the sample frame parts used in the test and the positional measurements related to the placement of the dovetail hole are given in Fig. 1.

*Adhesives*

Polyvinyl Acetate (PVAc) Adhesive: The dispersion, which has polyvinyl acetate as its basic substance, is an adhesive that contains a solid substance amount of 55%, a viscosity of 12-18 Pa.s. at a temperature of 20ºC, and 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 20ºC. 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/m3, its solid substance amount is 100%, and its viscosity is 1.5 Pa.s. The components were 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.

*Preparation of the Specimens*

It was envisaged to prepare a total of 80 each specimens [1 (material type) x 4 (adhesive types) x 2 (loading type) x 10 (number of tests repeated) = 80] for the determination of the bending moment capacity under diagonal tensile and compression loadings of the frame corner joints with dovetail fitting with three different types of adhesive (PVAc, PU and CA) and without adhesive on the MDF frames. The general principles given in ASTM-D 143-94 were complied with in the preparation of the specimens. The MDF boards were separated into pieces with a width of 50 ± 1 mm in order to obtain the specimens on which the tests would be made. From the pieces obtained, a total of 160 each pieces were prepared by cutting them to have a 150±1 mm length and mitered in one corner in a manner to produce a frame corner of 150 x 150 mm. A dovetail hole was opened on these pieces for the dovetail fitting in a manner so that it would be at the exact center of the right angle sides. From these pieces, 20 each the experimental pieces were formed without adhesive, 20 each bonded with PVAc adhesive, 20 each bonded with PU adhesive, and 20 each bonded with CA adhesive with dovetail fitting. Immediately after coating adhesives on the joining places for the bonded pieces,

the dovetail fitting was hammered, and the frame corner test specimens obtained were left to dry. The unbonded specimens were joined only by hammering the dovetail fitting. Additionally, 60 pieces without dovetail fitting were prepared in order to compare adhesives bonding strengths under diagonal tensile and compression loadings. Pieces were formed of 20 each bonded with PVAc adhesive, 20 each bonded with PU adhesive, and 20 each bonded with CA adhesive without dovetail fitting. Subsequently, the specimens were kept in a climatization chamber at a temperature of 20 + 2ºC and a relative humidity of 65 + 5% until they reached an unchanging weight.

## Methods

The specimens were subjected to the diagonal tensile and compression tests in a 10-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. 1 was applied. The loading speed of the machine throughout the tests was adjusted to 5 mm/minute. The loading continued until there was a separation or breaking at the joining places of the specimens, and the load (Fmax) at this instant was determined and recorded. Subsequently, the bending moment capacity under diagonal compression and tensile loadings were calculated with these values.
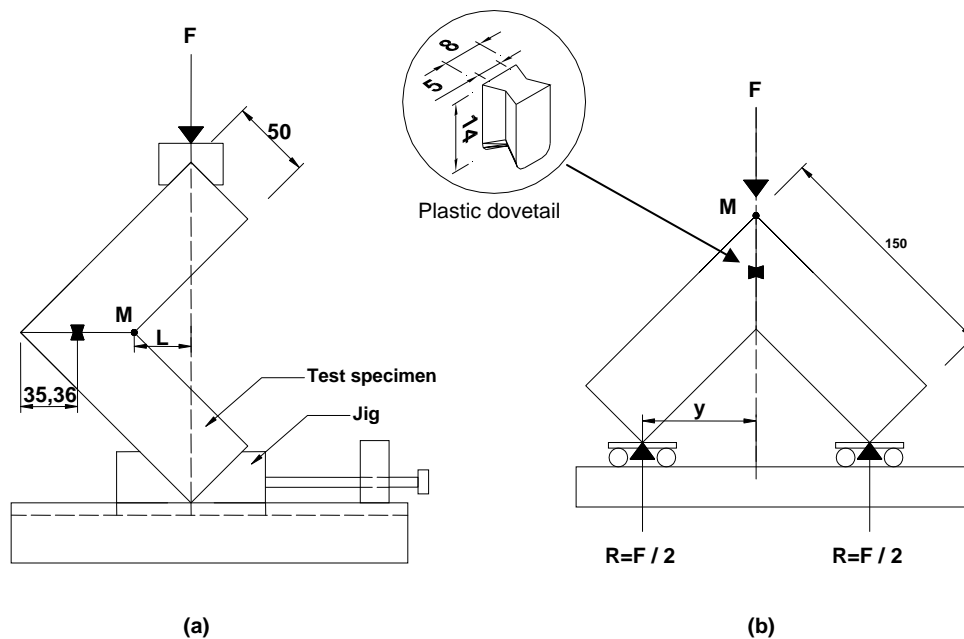


**Fig. 1.** Diagonal compression (a) and tensile (b) test system diagram (R=reaction forces)

The formulas given below were used in the determination of the bending moment capacity under diagonal compression loading of the specimens:

$$M_{dc} = \ F_{max} * L \ (Nm) \tag{1}$$

Here, $M_{dc}$ is the bending moment capacity under diagonal compression loading (Nm), $F_{max}$ is the force at the moment of separation or breaking (N), and $L$ is the moment arm (0.0353 m).

The bending moment capacity under diagonal tensile loading of each specimen was calculated with the equation given below,

$$M_{dt} = F_{max}/2 * y \ (Nm) \tag{2}$$

where $M_{dt}$ is the bending moment capacity under diagonal tensile loading (Nm), $F_{max}$ is the force at the moment of separation or breaking (N), and $y$ is the moment arm (0.0707 m).

The bonding strengths of the adhesives under diagonal tensile and compression loadings were calculated with the equation given below,

$$BS = F_{max} / A \ (N/mm^2) \tag{3}$$

where $BS$ is the bonding strength of the adhesives under diagonal tensile or compression loading (N/mm$^2$), $F_{max}$ is the force at the moment of separation or breaking (N), and $A$ is the bonding area (1414 mm$^2$).

The one-way ANOVA test was used in the determination of the effect of adhesive types on the bending moment capacity. In case the difference between the groups was significant, a comparison was made with the Duncan's Multiple Range Test. The SPPS 11.5 software was used in statistical analysis.

## RESULTS AND DISCUSSION

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

As can be seen from the figure, the highest bending moment capacity under diagonal compression loading (72.04 Nm) was obtained in the specimens bonded with PVAc adhesive, and this was followed at 58.38 Nm in the specimens bonded with PU adhesive. The bending moment capacity under diagonal compression loading of the miter corner joints with dovetail fittings in which adhesive was not used was 50.83 Nm, and the lowest bending moment capacity under diagonal compression loading (49.84 Nm) was in the specimens bonded with CA adhesive.

The highest bending moment capacity under diagonal tensile loading (46.09 Nm) was obtained in the specimens bonded with CA adhesive. This was followed by the specimens bonded with PVAc and PU adhesives. The lowest bending moment capacity under diagonal tensile loading (32.66 Nm) was obtained in the unbonded specimens.
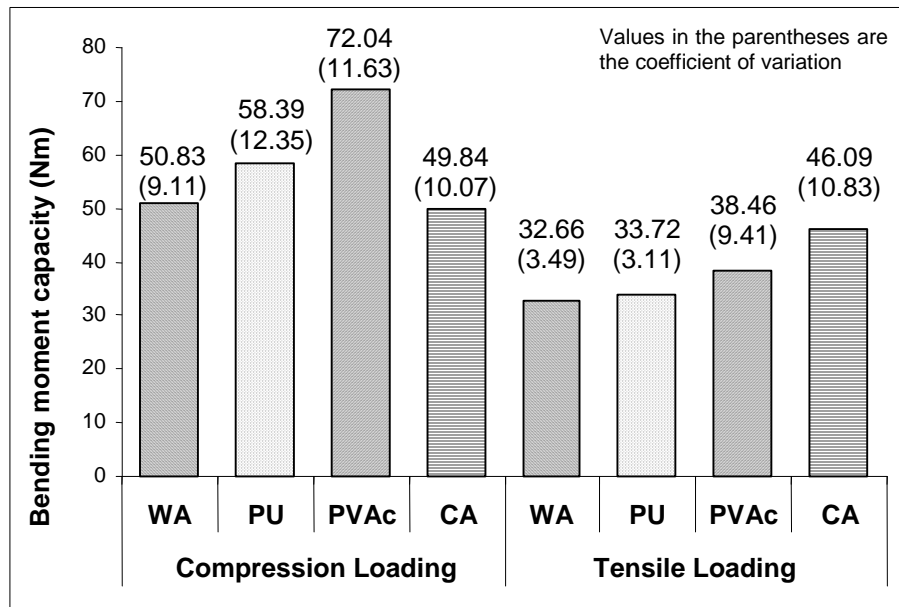
**Fig. 2.** The bending moment capacity and coefficient of variation values under diagonal tensile and compression loadings of the miter corner joints with dovetail fitting attached on the MDF frames with different types of adhesives and without adhesive

Bending moment capacities of the specimens under tensile loading were lower than that of compression loading for all the adhesives and without adhesives. But the difference between the evaluations of CA adhesive was pretty small. This might be due to the inflexible nature of the CA adhesive. It is more proper to use bending moment capacity under tensile loading than compression loading to determine the joint strength of this type of joint. This is because, when a frame door is exposed to a load, two opposite corners are forced under tensile load, while the other two opposite corners simultaneously experience compression loading. So bending moment capacity under tensile load, which is lower, should be used to evaluate the joint strength.

At first, failure occurred in the bond line both for the compression and tensile loading, and after that a deformation occurred at the edges of fitting hole. It might be construed that pressure produced by dovetail fitting was not enough to achieve a strong bonding.

The bonding strengths of the adhesives were determined by testing joints bonded with PVAc, PU, and CA adhesives without dovetail fitting under the same diagonal tensile and compression loading. The bonding strength of the adhesives under diagonal tensile loading were obtained as 1.19 $N/mm^2$, 1.46 $N/mm^2$, and 1.48 $N/mm^2$ in samples bonded with PVAc, CA, and PU adhesives, respectively. Bonding strength values under diagonal compression loading were obtained as 1.18 $N/mm^2$, 1.57 $N/mm^2$, and 1.79 $N/mm^2$ in joints bonded with PU, CA, and PVAc adhesives, respectively.

The one-way Anova test was used at the end of the tests for the analysis of whether or not there was a significant difference in the bending moment capacity values under diagonal tensile and compression loading of the specimens (Table 1).

**Table 1.** Analysis of Variance

| Bending moment capacity under diagonal compression load | | | | | |
|---|---|---|---|---|---|
| Source of Variance | Sum of Squares | Degree of Freedom | Mean Square | F Ratio | p |
| Adhesive Types | 3150.68 | 3 | 1050.22 | 5.28 | 0.004 |
| Residual (Error) | 7155.18 | 36 | 198.75 | | |
| Total | 10305.87 | 39 | | | |

| Bending moment capacity under diagonal tensile load | | | | | |
|---|---|---|---|---|---|
| Source of Variance | Sum of Squares | Degree of Freedom | Mean Square | F Ratio | p |
| Adhesive Types | 1122.49 | 3 | 374.16 | 36.93 | 0.000 |
| Residual (Error) | 364.74 | 36 | 10.13 | | |
| Total | 1487.23 | 39 | | | |

The bending moment capacity values were evaluated under diagonal compression and tensile loading of the mitered frame corner joints with dovetail fitting attached with different types of adhesives and without adhesives.

According to this, it was determined that there was a significant difference among the bending moment capacity values under diagonal compression and tensile loading occurring according to the adhesive combinations with α=0.05 significance and 95% confidence level, and that this difference was significant ($p<0.05$) (Table 1).

The Duncan's Multiple Range Test was applied to determine among which groups there was a significant difference, and the homogeneous groups emerging at the end of the test are given in Table 2.

**Table 2.** The Homogeneous Groups of the Bending Moment Capacity Under Diagonal Compression and Tensile Loadings According to the Types of Adhesive

| Bending moment capacity Under Diagonal Compression Load | | | Bending moment capacity Under Diagonal Tensile Load | | |
|---|---|---|---|---|---|
| Adhesives | Mean | HG | Adhesives | Mean | HG |
| CA | 49.84 | a | WA | 32.66 | a |
| WA | 50.83 | a | PU | 33.72 | a |
| PU | 58.39 | a | PVAc | 38.46 | b |
| PVAc | 72.04 | b | CA | 46.09 | c |

(HG) Different letters in a column refer to significant differences among the adhesives at 0.05 confidence level.

As can be seen from the table, since the bending moment capacity values under diagonal compression loading of the miter frame corner joints with dovetail fittings attached with CA and PU adhesives and without adhesive (WA) are in the same group, the apparent differences among them were insignificant. The bending moment capacity values under diagonal compression loading was the highest in the joints with PVAc adhesive, since it forms a separate homogeneity group. The PVAc adhesive has a flexible bond structure. As stated by Tankut (2007), the relative flexibility of the PVAc adhesive presumably allows some relative movement of the parts of the joint so that the internal stresses resulting from the applied load are distributed more uniformly between the bond line on the faces of the joints and the points of contact between the frame parts and the

dovetail. The mechanical interlock between the frame parts and dovetail probably contributes more to the strength of joints assembled with PVAc adhesive than it does in joints assembled with the less flexible PU and CA adhesives. According to this, it is necessary to use PVAc or a similarly effective adhesive to increase the bending moment capacity of the joints. Since the bending moment capacity values under diagonal compression loading of the joints made with CA and PU adhesives and the joints made without using adhesive are the same statistically, any of these types of adhesives can be preferred for these types of joints.

Since the bending moment capacity values under diagonal tensile loading of the miter frame corner joints with dovetail fitting attached with PU adhesive and without adhesive (WA) are in the same group, the apparent difference between them was insignificant. The joints with CA adhesive produced the highest bending moment capacity under diagonal tensile loading. The joints with PVAc adhesive had the second highest bending moment capacity under diagonal tensile loading. In this situation, the CA adhesive should be preferred in order to obtain higher bending moment capacity under diagonal tensile loading in the miter frame corner joints with dovetail fitting.

## CONCLUSIONS

Since it is not necessary to keep the frame pressed for the adhesive to harden in miter frame corner joints with dovetail fitting, the shortness of the hardening period of the adhesive does not constitute an advantage. Accordingly, it would be advantageous to use the PVAc adhesive for strength in these types of frames, since that adhesive produced the highest bending moment capacity value under diagonal compression loading and the second highest value under diagonal tensile loading.

As was stated in the introduction, there are some studies related to 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.

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