DIAGONAL TENSILE STRENGTH OF AN ORIENTED STRAND-BOARD (OSB) FRAME WITH DOVETAIL CORNER JOINT

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It was aimed in this study to determine the effect of the number of joints in frames produced from Oriented Strand Board (OSB) and of the type of adhesive on the diagonal tensile strength (DTS) of the frame. With this objective, a total of 152 specimens were prepared from OSB in accordance with the principles in the TS 2470 test standard. The diagonal tensile test was applied to the specimens in the universal test equipment in accordance with ASTM-D 1037. According to the statistical analysis of the data obtained from the tests, the number of dovetail joints and the type of adhesive had significant effects on the DTS. The highest DTS (0.117 N/mm^2) was obtained in the specimens with a single dovetail joint and bonded with the PVAc adhesive. This alternative was followed by the specimens with a double dovetail joint bonded with the PVAc adhesive (0.078 N/mm^2) and the specimens with a single dovetail joint bonded with the PU adhesive (0.073 N/mm^2). The lowest DTS occurred in the specimens with single and double joints without adhesive. According to these results, adhesive should definitely be used in the corner joining of the dovetail joints, and the single dovetail joint joining type bonded with PVAc adhesive is preferred.

Keywords: Frame corner joining; Dovetail joint; OSB; Tensile strength

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INTRODUCTION

Frame construction is an alternative construction form used in a widespread manner in construction elements, such as doors, windows and dividing wall panels, and in furniture elements and furniture doors, such as tables, coffee tables, and showcases. The appearance of the frame, just as it can be in basic geometric forms, such as a square, rectangle, oval, and circle, it can also be in curved forms, such as a combination of these with free external lines.

Perpendicular, horizontal, or diagonal loads occur at the joining points of the frame elements connected to the masses of the structural elements and temporary loads. The intensity of these loads varies according to the place of use of the frame. It is necessary for the resistance of the frame to be sufficient to respond to these loads. Otherwise, initially openings will occur in the joints and subsequently, by undergoing disintegration into pieces, the integrity of the frame is lost. The resistance to such loads by the frame varies in connection with the materials used in the construction of the carrying elements, the type of joining, the type of adhesive used in the joining, and the method of fixing the closing element to the empty space of the frame (Eckelman 1971; Hill and Eckelman 1973; Englesson 1973; Molain and Carroll 1990; Zahn 1991; Zhang and Eckelman 1993; Efe 1994; Ozcifci 1995; Eckelman and Lin 1997; Ors and Efe 1998; Kasal 1998; Kharaouf et al. 1999; Kap 1999; Imirzi 2000; Falk et al. 2001; Efe and Imirzi 2001; Ors et al. 2001; Hwang and Komatsu 2002; Yadama et al. 2002; Sawata and Yasumura 2002; Erdil et al. 2003; Kurt 2003; Kasal 2004; Malkocoglu and Cetin 2009).

Oriented strand board (OSB) is manufactured from the logs of renewable and fast-growing trees such as aspen poplar, southern yellow pine, and other suitable species. Logs are cut to length and run through bark-removing equipment. The strands ranging from 2 in. to 4 in. long (50 to 100 mm), approximately 1 in. wide (25 mm) and 0.025 in thickness (0.6 mm) are cut from the logs, deposited into wet bins, dried to the appropriate moisture content, sorted, and blended with generally phenol formaldehyde or isocyanate resin and small amount of wax in order to improve internal strength and rigidity of panel and provide moisture and water absorption resistance . The strands are formed into large continuous mats. These mats are oriented in cross-directional layers for increased strength, then pressed at a high temperature and pressure to form panels. Physical and mechanical properties of OSB change depending on the wood characteristics (species, density, etc.), strand properties (dimension, geometry, orientation, etc.), resin characteristics (type, content, solvents, etc.), and the variables of manufacturing process (pressing temperature, pressure, drying, face-to-core ratio, etc.).

In all wood gluing processes, there are six factors operating, any one or all of which can vary controllably or uncontrollably, and they may affect the gluing process either directly or indirectly. These factors are adhesive composition factors (viscosity, strength, durability, pH, solvents, diluents, fillers, etc.), wood property factors (species, density, sapwood-heartwood proportions, permeability, reaction wood, anisotropy, etc), wood preliminary factors (cutting to size, surface roughness, grain angle, moisture content, impregnants, etc.), adhesive application factors (storage, weighing, mixing, application method, assembly time, pressure, temperature, etc.), wood geometry factors (element dimension, grain, structure, etc.), and product service factors (external and internal stresses, creep, relaxation, environment, heat, etc.). The bond formation and bond performance can be affected by the curing process and the solid properties of adhesives and how they respond to stress and tensile influences (Marra 1992). It was stated that while sticking wooden material together with adhesives, adhesion depends on many factors such as wettability qualities of the surface, penetration, reaction, polymerization, porosity, pH, moisture gradient, extractive materials, chemical interactions, surface free energy, surface area, and which surface of the wood (radial section, tangent section, or cross section) will be in contact with the adhesive (Rowell 1995; Mahlberg et al. 1998; Winfield et al. 2001). In the processes of bonding wood veneer or laminate, a high adhesion strength is required. By contrast, when applying veneers to the surfaces of MDF or ply-wood boards, it may not be necessary to use a contact adhesive. In such cases it is advisable to economize and avoid unnecessary amounts; for example one may use PVAc or UF adhesive, applying 150 g adhesive per square meter (Budakci 2010).

Recently, the preference for plastic dovetail joints in the assembly of frame parts to each other has become gradually more widespread. The important reasons for this preference are (1) that the opposite channels can be opened with greater facility and (2) after the joining is made, it will no longer be necessary for them to remain in a tight position until the adhesive layer hardens. Because of this, more frame assemblies can be made in a unit time. It is thought that factors such as the materials of the frame pieces, the number of dovetail joints, the location at the joining place of the joints, and the adhesive type used all have important influence on this joining strength. Sufficient research related to this type of joining was not encountered in a study of the literature on this subject, despite that fact that it is currently the most prevalent method of joining used in frame joining. In this study, it was aimed to determine the effect of the number of dovetail joints in cases where OSB is used as a carrying element in frames and of the type of adhesive on the diagonal tensile strength of the frame.

EXPERIMENTAL

Materials

Oriented Strand Board (OSB)

Oriented Strand Board (OSB) was used in the production of the frame parts. Some of the characteristics of the OSB are given in Table 1 (Ozkaya 2002; Rebollar et al. 2007).

Table 1. Basic Characteristics of the OSB Panels

Thickness (mm)	18	**Modulus of Elasticity (MPa)**	5700 ± 1400 (//)
Density (g/cm^3)	0.650		2000 ± 500 (⊥)
Quality Class (EN 300)	1	**Bending Strength (Mpa)**	30 ± 7 (//)
Tensile Strength (N/mm^2) (⊥)	0.35 ± 0.15		15 ± 4 (⊥)

Polyvinylacetate (PVAc) Adhesive

The PVAc used is a dispersion adhesive that contains 55% of solids content, a viscosity value of 12 to 18 Pa.s at a temperature of 20ºC, and a density of 1080 kg/m^3. It was used in accordance with the recommendations of the manufacturer (Loctite 2004).

Polyurethane (PU) Adhesive

The PU product is a single component adhesive. It has 100% of the undiluted liquid ingredient, a density of 1200 kg/m^3, and a viscosity value of 4 to 5 Pa.s at a temperature of 20ºC. It was used in accordance with the recommendations of the manufacturer (Boypox 2009).

Cyanoacrylate (CA) Adhesive

This product is a double-component (cyanoacrylate and amines) adhesive. Its density is 1060 kg/m^3, with a 100% of the undiluted liquid ingredient and a viscosity of 1.5 Pa.s. The components are applied separately to the surfaces to be bonded. It is sufficient for bonding to hold the parts together for up to 10 seconds after the parts are joined. Complete hardening is realized in 24 hours. It was used in accordance with the recommendations of the manufacturer (Somafix 2009).

Dovetail Joint

The frame parts and corners were joined with part of the PVC dovetail joint, as shown in Fig. 1.

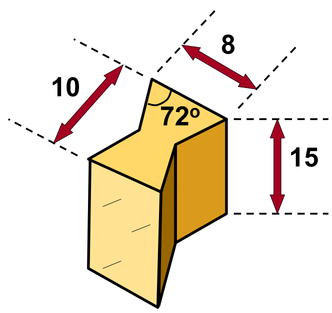


Fig. 1. Part of The PVC dovetail joint. The measurements are in mm.

Preparation of the Experimental Specimens

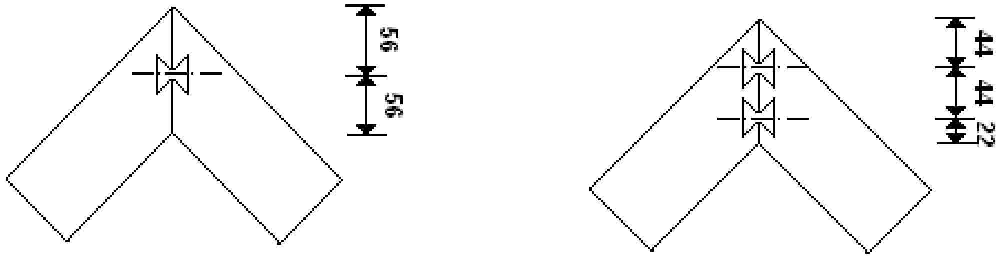
The frame parts were prepared according to the order of procedures given below and in accordance with the principles of TS 2470.

a. Frame pieces were cut having the rough dimensions of 90x210 mm from OSB having the dimensions of 1220×2440 mm.
b. The rough pieces were brought to 12% air dried humidity by being held in a climatization chamber at a temperature of 20 ± 2ºC and a relative humidity of 65% ± 3.
c. The pieces were cut to net measurements having the dimensions of 80x200 mm.
d. An end of the pieces was cut as a miter and tenon with a 45º angle, and dovetail canals were opened according to the joining type.
e. Adhesive was spread to the surfaces cut as a miter and tenon and to the surfaces where canals were opened, and the frame pieces were kept in position until the adhesive layer hardened.
f. The frame pieces so prepared were placed and kept in a climatization chamber having a temperature of 20 ± 2ºC and a relative humidity of 65% ± 3 until they reached constant moisture content (12% humidity).
g. The specimens were placed in plastic bags so that their humidity values would not vary, and the bags were kept sealed until testing.

A total of 152 specimens were prepared together with the control specimens to determine the effect of the three different adhesive types and two different joint positions on the diagonal tensile strength. The frame pieces prepared and the positions of the dovetail joints on the frame pieces are shown in Fig. 2.

Methods

Diagonal tensile strength (DTS) tests were carried out with a four-ton universal test device with the loading model shown in Fig. 3 according to the principles of the ASTM-D1037 method. A diagonal loading was applied to each specimen at a speed of 2 mm/min.



(a) (b)

Fig. 2. Formats of single and double dovetail joints. The measurements are in mm.

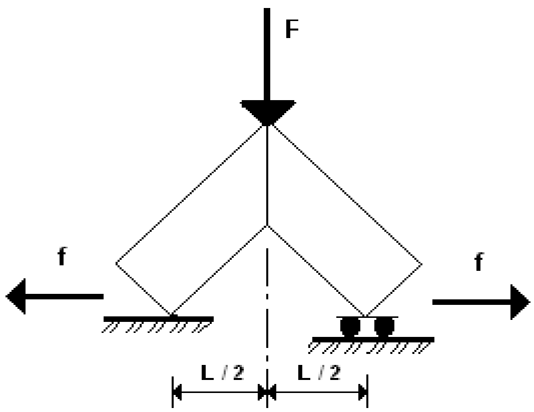


Fig. 3. The model for applying diagonal tensile strength

The maximum strength (F_{max}) at the moment of deflection, which emerged as a result of the diagonal loading, was determined, and the diagonal tensile strength (DTS) of the specimens was found from Eq. (1):

$$T = \frac{F_{max}}{A} \qquad N/\text{mm}^2 \tag{1}$$

Here, (N) is the maximum strength at the moment of deflection (N), and A is the area of influence of the strength applied (mm^2). The area of influence of the single and double dovetail joint specimens was calculated with the formulas given below (Fig.4):

$$A_{single} = [(d \,.\, \ell) - (b \,.\, h)] + [h (4 c + 2 t) + a (b + t)] \quad \text{(For single dovetail)} \tag{2}$$

$$A_{double} = [(d \,.\, \ell) - 2 (b \,.\, h)] + 2 [h (4 c + 2 t) + a (b + t)] \quad \text{(For double dovetail)} \tag{3}$$

The following are explanations of the letters in the formulas:

d : Thickness of the panel,
h : Height of the dovetail,
ℓ : Width of the panel,
c : Side surface width of the dovetail,
b : Inner width of the dovetail,
t : Outer width of the dovetail,
a : Depth of the dovetail

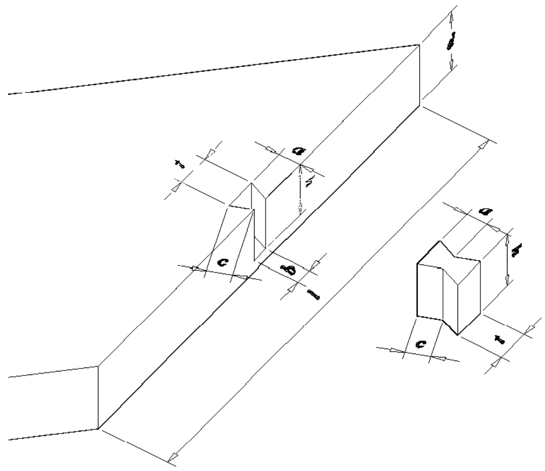


Fig. 4. Schematic illustration of surface area formulas (Equation 2 and 3).

The SPSS package program and multiple analysis of variance were applied in the statistical analysis of the data obtained in the tests. The effects of the adhesive type and the number of joints on the diagonal tensile strength were determined by analysis of variance (α=0.05). The diagonal tensile strength influence levels of the factors were determined by applying the Duncan Homogeneity Test to the influential factors within the groups and among the groups.

RESULTS AND DISCUSSION

The average diagonal tensile strength values obtained according to the number of joints and the adhesive types are given in Table 2. As it can be seen from the table, the highest diagonal tensile strength was obtained in the specimens with a single dovetail joint bonded with PVAc adhesive. The lowest diagonal tensile strength occurred in the specimens with a single dovetail joint without adhesive.

Table 2. Diagonal Tensile Strength Values According to the Number of Joints and the Adhesive Types

Variables		Diagonal tensile strength (N/mm^2)	
No. of Joints	Adhesive Type	$\bar{x}$	*s*
Single	PVA$_C$	0.117	0.017
	Polyurethane	0.065	0.013
	Cyano-acrylate	0.073	0.012
	Control	0.014	0.006
Double	PVA$_C$	0.078	0.010
	Polyurethane	0.040	0.007
	Cyano-acrylate	0.051	0.010
	Control	0.018	0.007

Using the values from Table 2, an analysis of variance was made with the objective of determining whether or not the number of joints and the adhesive type had a meaningful influence on diagonal tensile strength (Table 3). As it can be seen in Table 3, since $p<0.05$ in every case, the number of joints and the adhesive type as well as the number of joints and the adhesive type as a pair had significant effects on the diagonal tensile strength.

Table 3. Analysis of Variance Aimed at the Effect of the Number of Joints and the Adhesive Type on the Diagonal Tensile Strength

Variable	Average of squares	Degree of freedom	Average of squares	F value	p (α=0.05)
Joining	0.016	1	0.016	133.116	0.000*
Adhesive	0.128	3	0.043	357.113	0.000*
Joining x adhesive	0.010	3	0.003	27.010	0.000*
Error	0.017	144	0.000		
Total	0.665	152			

* : p-value < 0.05 is a significant difference.

The Effect of the Number of Dovetail Joints on the Diagonal Tensile Strength

The diagonal tensile strength values according to the number of joints and the homogeneous groups resulting based on these values are given in Table 4.

Table 4. The Tensile Strength Values and Homogeneous Groups According to the Type of Joining

Type of joining	$\bar{x}$ (N/mm^2).	*s*	H.G.
Single	0.067	0.001	A
Double	0.047	0.001	B

As can be seen from the table, there was a statistically significant difference between the diagonal tensile strength values of the single and double joint specimens. The DTS of the single joint specimens (0.067 N/mm^2) was higher compared to the double joint specimens (0.047 N/mm^2). Weak areas developed between the end points and the center joining line of the joints due to the dovetail form of the joint (Fig. 2). When tensile strength was applied, first of all, deformations started in this area, and later openings were formed in the zone of dovetail joints. It is thought that the DTS of the double joint specimens was lower because the area of the weak surface increased compared to the single joint specimens. Consequently, it would be more suitable to prefer a single joint for these types of joints.

The Effect of the Adhesive Type on the Diagonal Tensile Strength

The diagonal tensile strength values according to the adhesive type and the homogeneous groups occurring according to these values are given in Table 5.

Table 5. The Diagonal Tensile Strength Values and the Homogeneity Groups According to the Adhesive Types

Adhesive Type	DTS (N/mm^2)	*HG*
PVA_C	0.098	A
Polyurethane	0.052	C
Cyanoacrylate	0.062	B
Control	0.016	D

As can be seen from Table 5, there was a statistically significant difference among the diagonal tensile strength values according to the adhesive types. According to the adhesive types, the highest DTS was obtained in the specimens bonded with the PVAc adhesive, and this was followed by the specimens bonded with the CA and PU adhesives, respectively. The lowest DTS occurs in the joining without adhesive. According to these values, adhesive should definitely be used in these types of joints, and the PVAc adhesive should be preferred when there is a need to achieve a high DTS value.

Adhesive Type and the Number of Joints vs. Diagonal Tensile Strength

The DTS values according to the dual interaction of the number of joints and adhesive types are given in Table 6, along with the homogeneous groupings. As it can be seen from the table, there was a statistically significant difference between the DTS values for the dual interaction of the number of joints and the adhesive types. The highest DTS was obtained for the single joint specimens bonded with the PVAc adhesive, and this was followed by the single-joint specimens bonded with the PU adhesive and double joint specimens bonded with the PVAc adhesive. Furthermore, there was a statistically insignificant difference between the DTS values of the single-joint specimens bonded with the CA adhesive and the DTS values of the specimens bonded with the PVAc adhesive. On the other hand, with respect to the joining with adhesive, the lowest DTS occurred in the double joint specimens bonded with the PU adhesive. The single- and double-joint specimens without adhesive exhibited the lowest DTS values, and the difference between them was statistically insignificant.

Table 6. The DTS and Homogeneity Groups According to the Number of Joints and Adhesive Types

Number of Joints and Adhesive Types	**DTS (N/mm^2)**	***HG***
Single x PVAc	0.117	A
Single x PU	0.065	C
Single x CA	0.073	B
Single x Control	0.014	F
Double x PVAc	0.078	B
Double x PU	0.040	E
Double x CA	0.051	D
Double x Control	0.018	F

According to this data, the single dovetail joint joining type bonded with the PVAc adhesive should be preferred in the corner joining of dovetail joints.

DISCUSSION AND SUMMARY

In this study, the effect on the diagonal tensile strength (DTS) of the number of dovetail joints and of the adhesive type on the corner joining in frames produced from oriented strand board (OSB) were investigated. According to the statistical analyses of the data obtained from the tests, both the number of dovetail joints and the adhesive types in the frames made from OSB affected the DTS of the miter and tenon corner joining.

The DTS of the frame corner joining of the single dovetail joints were approximately 30% higher compared to the double dovetail joints. Weak areas developed between the joint canal and the surface of the cross-section between the joining due to the form of the dovetail (Fig. 2). Deformations and separations (breaks) started first in this area when tensile force was applied, and later openings formed on the surface of the cross-section in between. It is thought that the DTS of the double-joint specimens was lower compared to the single-joint specimens due to increases in the weak areas. Consequently, it would be more suitable to prefer single joints in these types of joining.

The highest DTS was obtained in the frames bonded with the PVAc adhesive in the dovetail joint frames made from OSB. The DTS of the specimens bonded with the PVAc adhesive was approximately 2-fold higher than the DTS of specimens bonded with the PU adhesive and 35% higher compared to the DTS of specimens bonded with the CA. The DTS of the specimens bonded with the PVAc adhesive was 6-fold higher compared to the specimens without adhesive. The fact that the layers of the PU and CA adhesives produce a structure that is crystallized and which has cavities after hardening, coupled with the fact that this structure can encounter rapid deformation in case of any loading, could explains this result.

According to the results of the studies made previously, the PVAc adhesive produces a higher strength compared to the PU and CA adhesives in the mortise and tenon joints and treenail furniture joining (Altinok et al. 2000; Malkocoglu and Arz 2007). Furthermore, in the frame corner joining where Medium Density Fiberboard (MDF) and poplar materials are used, the single dovetail joint showed a higher tensile strength compared to the double dovetail joints (Malkocoglu and Cetin 2009; Kilic et al. 2009). These results are also in conformity with the results of this study.

According to these results, it is proposed for higher joint strength that adhesive should definitely be used in these types of joints, that PVAc should be preferred as an adhesive, and that the joints should be made with a single dovetail joint.

Since strength resides primarily in the configuration of the joint, the major criteria out of the strength in choice of adhesives are ease of use, instant holding power, speed of cure, developing strength at room temperature, and gap-filling tendency. The PVAc adhesive is also suitable for the above-mentioned criteria.

Particle board and medium density fiberboard (MDF) are usually used in the manufacturing of the furniture frames. To create aesthetic difference in the decoration, OSB, as an alternative material, has been used more and more instead of particle board and MDF by applying special finishing techniques. The results will be useful for the frame manufacturers who want to use OSB as an alternative material.

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