Impacts of the Dovetail Tooth Angle on Diagonal Tensile Strength in Leg-To-Rail Joints

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Effects on diagonal tensile strength were evaluated for the preparation of dovetail leg-to-rail joints, end to side grain joints, and dowel joints, which are applied for furniture leg-to-rail joints in various tooth angles. In compliance with the rules of ASTM D 1037, the diagonal tensile test was applied to the corners obtained with polyvinyl acetate (PVAc) and polyurethane (D-VTKA = Desmodur-Vinyl Triechetonole acetate) adhesives after drilling the joints on the specimens prepared from Oriental Beech (*Fagus orientalis* Lipsky), European Oak (*Quercus petreae* Liebl.), and Scotch Pine (*Pinus sylvestris* Lipsky) at 75º, 78º, 81º and 84º. The highest diagonal tensile strength in terms of wood type, joining technique and adhesive type was found for O+P+II (1,184 N/mm^2), and the lowest was S+D+V (0,2687 N/mm^2). In terms of diagonal tensile strength, PVAc adhesive and 78º dovetail joint technique can be recommended for leg-to-rail joints.

Keywords: Diagonal tensile strength, joint angle, dovetail leg-to-rail joint, adhesives, wood

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INTRODUCTION

While designing furniture components, their functions, sizes, and aesthetics are given a particular importance. The furniture is purchased by taking one or all of these factors into account. According to the place and purpose of use, the cost may be of secondary importance. Apart from the factors, the lifetime of the furniture is directly affected by the construction that forms it (Ors *et al.* 1999).

The furniture, depending on the intended use, is faced a variety of mechanical stresses. According to the form of the force that has an impact on these stresses, the deformations such as openings or relaxation in the joints of furniture elements, bending, cracking, or breaks in the elements occur. The size of the deformation affecting the robustness and quality varies according to type of adhesive and woods and according to the construction which is applied in the joints (Altinok 1998).

The factors that affect the determination of the durability of furniture are the material used, the construction that is chosen, and the strength of the joint formed by arranging the auxiliary materials in a harmony. Deformations in the joints come into being as a result of mechanical stress by being exposed to external force. Many studies have been conducted to determine these deformations and the stresses and strains to which the joints will be exposed during usage (Eren and Eckelman 1998).

After the box-type furniture corners have been prepared from the Oriental beech, sessile oak, and Scotch pine and medium density fiberboard at the tooth angles of 75º, 78º, 81º, 84º and 87º and joined with polyvinyl acetate and polyurethane adhesives, the diagonal compression and diagonal tensile tests have been performed and the tooth angle 81º has produced the best result in terms of compression and tensile strength performance (Ustundag 2008).

In the wood drawer, the highest tensile strength has been found in the screw joint that is joined by using medium density fiberboard and polyvinyl acetate and that is parallel to the mounting direction, and the lowest tensile strength has been found in the tongue and groove joints, which are joined by using medium density fiberboard and polyvinyl acetate and which is made parallel to the mounting direction (Gode 2005).

Tensile strength tests have been performed in the Scotch pine, Oriental beech and sessile oak specimens by joining them with D-VTKA adhesive in the transversal and radial directions. Tensile strength tests have been performed by joining the particle boards and fiberboards whose sides are solid and not solid with PVAc adhesive. The highest tensile strength has been reported in the fiberboard whose sides are solid and in the Oriental beech in the transversal direction (Ors *et al.* 1999)

In the study made in order to determine the impact of the dilution of PVAc with water in different proportions on the bonding strength of the Oriental beech, sessile oak and Scotch pine, it has been reported that the highest value has been obtained from the viscosity of the Oriental beech + packaging and the lowest value has been obtained from the Scotch pine + the adhesive that is added 40% water (Atar 2007)

At the end of the study made in order to determine the impacts of the material type, joining technique, and adhesive type in the corner joints of the furniture drawer on the diagonal tensile strength, the highest tensile strength in terms of tensile strength has been found in the box joint (finger joint), whereas the lowest tensile strength has been found in the dowel joint (Gunes 2006).

Ors *et al.* (2000) reported that 6, 8 and 10 mm dowels, the edges of which are covered with 5, 8, 12 mm solid Oriental beech material and which are on the waferboard that is not solid, were bonded with PVAc adhesive by drilling holes in the depth of 25 mm. The highest dowel tensile strength was observed in the solid waferboard (8 mm) and in the 6 mm dowel, whereas the lowest tensile strength was in the 10 mm dowel and in the waferboard that is not solid.

Fiberboard has gained an advantage over the particle board in the dowel joint processes, and it has been reported that PVAc adhesive showed the best result among other adhesives (Efe and Kasal 2000).

After some factors (distance between the hole centers of biscuit type foreign laths (çıta), the distance between the outer edges of the board, board-type adhesion technique) affecting the resistance properties of the corner joints prepared with the biscuit type foreign laths were studied, the strength was found high in the fiberboard in the joints with adhesive and without adhesive, and it was found that 15 cm distance between the biscuit centers increased the strength in comparison with 10 and 12,5 cm distances; and 5-6, 5-7, 5 cm distances between the biscuit laths and the edges would not create any difference in terms of strength (Tankut 2004).

PVAc D4 adhesive has shown the best resistance against tensile forces. The dowel joint has shown the best resistance in joint technique; and biscuit joint has shown the best resistance in the compression tests (Demirel 2008).

In order to determine the effects of the dovetail tooth angles on the tensile strength in longitudinal direction in the dovetail end to end-grain joint, Oriental beech, Scotch pine, and European oak woods were bonded with D-VTKA and PVAc, and the tensile strength test was applied. The highest tensile strength was found in the sessile oak, while the lowest was found in the Scotch pine. The highest tensile strength was found in PVAc in terms of adhesive, and the lowest was found for D–VTKA. The highest tensile strength was found in the angle 81, whereas the lowest was in the angle 84 in terms of tooth angle. End-on-end dovetail joints, sessile oak, PVAc adhesive and the angle 81 can provide advantage in terms of tensile strength (Atar *et al.* 2008).

As box furniture constructions are exposed to compression and tensile stress, it has been recommended to use the dowel joint type and the polymarine adhesive in corner joints of the box furniture produced from coated MDF (Medium density fiberboard) (Tas *et al.* 2007).

In order to study the effects of wood type and dowel and dovetail joint techniques on the column feet (from the midpoint) strength, Scotch pine, Oriental beech, and polyvinyl acetate adhesive were chosen. The highest compression strength was determined in the beech feet with the dovetail joint (Altinok 1998).

The highest tensile strength was seen in the beech with the screw joint according to the wood type and joint technique. The weakest strength was obtained in the Scotch pine with the end to side grain joints. In addition, according to the stress analysis in the tests, dowel joints gave better results, and end to side grain joints gave better results according to the strength transmission performance (Efe and Imirzi 2001).

This study was carried out to determine the impacts of different joint angles on the diagonal tensile strength of dovetail leg-to-rail joints; that is one of the leg and trail joints techniques.

EXPERIMENTAL

Material

Woods

In this study, wood materials were used by random selection method from sellers in Ankara sites from woods between Oriental beech (*Fagus orientalis* Lipsky.), European oak (*Quercus petraea* Lipsky), Scotch pine (*Pinus sylvestris* Lipsky). The wood materials were first class, and they had proper fiber directionality, did not have any cracks, knobs, color or density difference, and the annual rings were vertical to the surfaces. The specimens were prepared from sapwood according to TS 2470 standards (TS 2470, 1976). Lumber pieces were cut according to dimensions and stacked in storage areas where sunlight does not enter and where there was air circulation by putting lath between them and their air were made air-dried.

Adhesives

In this study, PVAc adhesives were preferred due to their common usage in the woodworking industry and massive furniture manufacturing because of easy application, quick hardening, being able to apply in room temperature, and being inflammable and odorless. Polyvinyl acetate (PVAc) and polyurethane (D-VTKA=desmodur-vinyl triechetonole acetate) adhesives, which are proper for cold pressing operations, were used.

Dovetail tooth opening blade

The study was carried out using driller-shaped blades, which are often used in dovetail thread fastening operations, such as are often used in massive table corners. A dovetail channel blade is shown in Fig. 1, and parts of the dovetail channel blade are listed in Fig. 1.

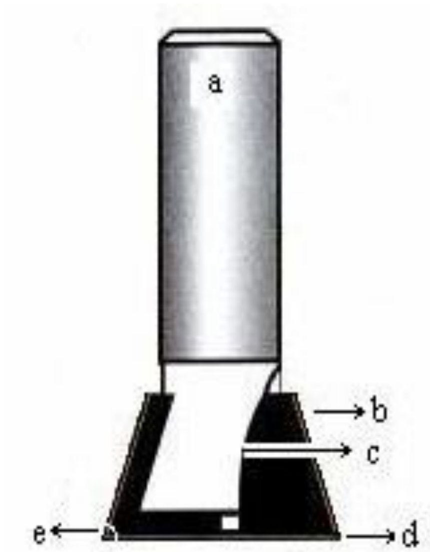

Fig. 1. Dovetail channel blade

Table 1. Parts of the Dovetail Channel Blade

Parts of the Dovetail Channel Blade	
a	Body
b	Cutting blade
c	Helix
d	Cutting Edge
e	Blade (tooth) angle

Surface areas of the joints used in the samples

The dovetail channel opening blade applied in the solid furniture was specially made at the angles of (75°, 78°, 81°, 84°) for this study. Adhesion surface areas of the joint types applied in the test samples are given in Table 2.

Table 2. Surface Areas of the Dovetail, Dowel and End to Side Grain Joints

Joint Technique	Area (mm^2)
75°	2916.13
78°	2820.21
81°	2725.15
84°	2631.66
Dowel	2858.64
End to side grain joint	3619.30

Method

Preparation of the test samples

Oriental Beech, European oak, and Scotch Pine as wood materials; polyvinyl acetate (PVA) and polyurethane (D-VTKA) as adhesives, dovetail tail, dowel, and end to side grain joint techniques at the angles of 75°, 78°, 81° and 84° as joining types were chosen. The force was applied so as to evaluate the diagonal tensile strength.

Dovetail joint test samples

Four different angles (75º, 78º, 81º, 84º) were applied in test specimens of the dovetail joint. Each test sample consists of two components A and B. The dovetail joint foot element was prepared as (A) 40 x 200 x 40 mm, and the recording element was prepared as (B) 21 x 50 x 160 mm. Measurements of the test specimens are given in Fig. 2. Dovetail pined joining elements were recessed on the face of the element A, and they were the tail in the end grain of element B during the process.

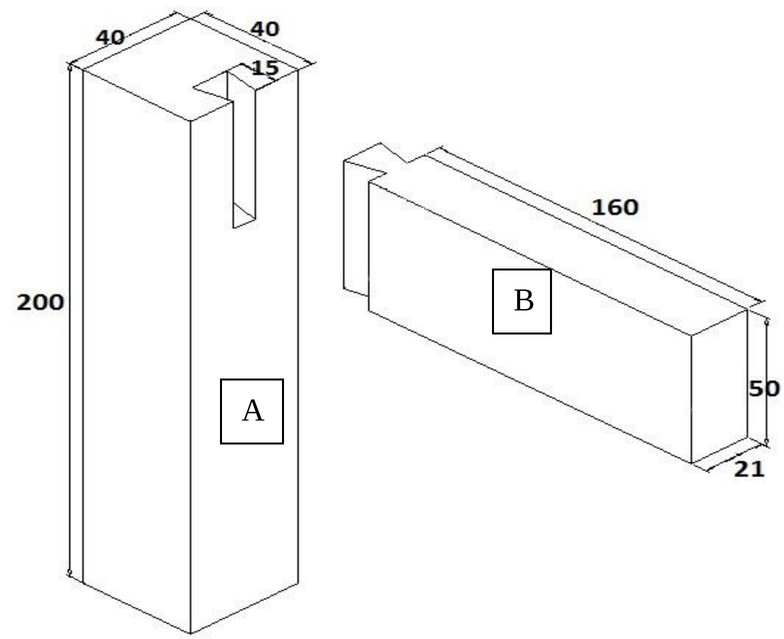

Fig. 2. Dovetail test sample (mm)

After the joining surfaces of the elements A (pins) and B (tail) were bonded, the specimens were mounted. The drawing of the test sample is shown in Figure 2. The mounted specimens were kept waiting at 20±2 C° temperature and relative humidity of 65% ± 3 until the test time.

Dowel joints test samples

Dowels in the size of 8 mm diameter and 32 mm length were used in the dowel joint. After the adhesives to be applied to the joining surfaces of the elements A and B were applied as 160–200 gr per m^2, the specimens were mounted. About 2 N/mm^2 force was applied in mounting processes, and after 24 hours, the press was opened. A drawing of the test specimens is shown in Fig. 3. The mounted specimens were kept waiting at 20±2 C° temperature and relative humidity of 65% ± 3 until the test time.

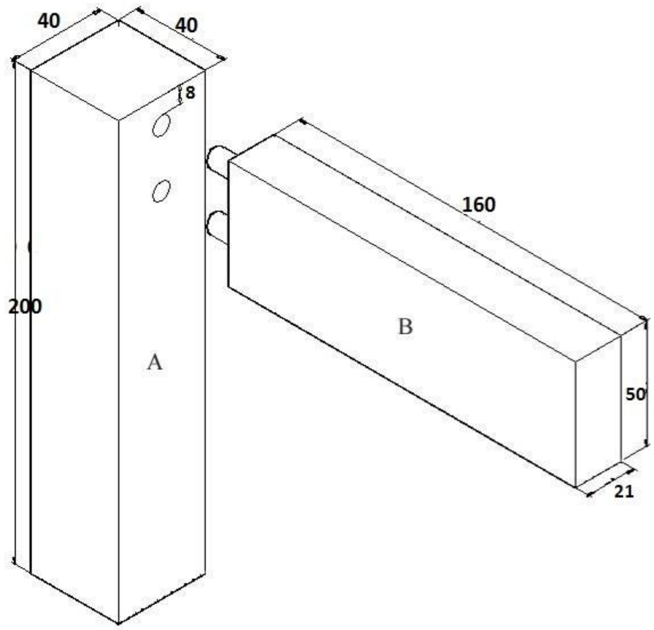

Fig. 3. Wooden dowels test sample (mm)

Mortise and tenon joints test samples

In end to side grain joints test specimens, the mortise was opened for the foot devices with the drill bit in 8 mm diameter, and the tenon was opened to the recording element. After the adhesives to be applied to the joining surfaces of the elements A and B were applied as 160 to 200 g per m^{2,} the specimens were mounted. 2 N/mm^2 force was applied in mounting processes and after 24 hours, the press was opened. A drawing of the test specimens is shown in Fig. 4. The mounted specimens were kept waiting at 20±2 C° temperature and relative humidity of 65% ± 3 until the test time.

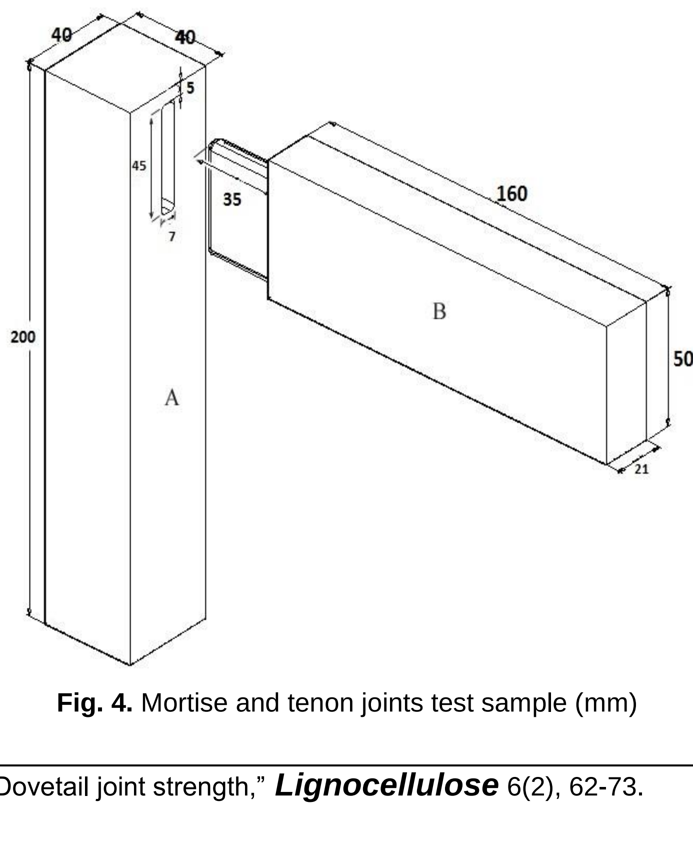

Fig. 4. Mortise and tenon joints test sample (mm)

Test equipment

Universal Test Equipment having a 5 ton capacity, which is present in Gazi University technical Education faculty Furniture and Decoration department mechanics laboratory, was used in tests. Loading speed can be adjusted manually. The loading speed was adjusted as 2 mm/min, which provided an application period between 30 and 60 seconds. ASTM D 1037 principles were followed in the tests. Forces of test samples during deformation were recorded in Newtons (N). The robustness of furniture is generally determined by the robustness of the joining location, which is formed by joining of selected construction and ancillary tools in harmony. Compelling forces, which correspond to rail to leg joints, may cause the furniture to undergo progressive deformation with the passage of time. Several studies were made for determining these deformations by characterizing the stresses and strains to which the joints will be exposed during usage (TS 2470, 1976). Similar studies were utilized in test method, and assemblies related to this are shown in Fig. 5.

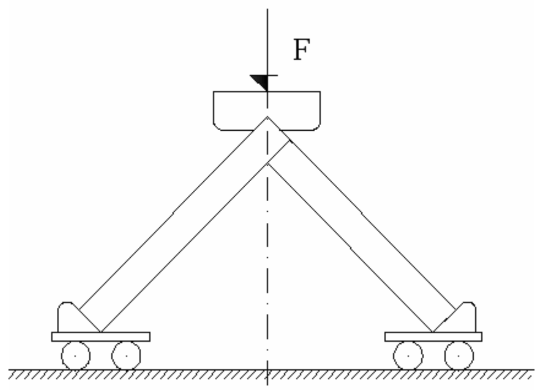

Fig. 5. Diagonal tensile testing setup

Data Analysis

Multiple variance analysis (MANOVA) was used to charcterize the statistical importance of the performances evaluated in this work. The DUNCAN test was applied to indicate the significance level on the condition that mutual interaction of the factors becomes significant with 5% error margin.

RESULTS AND DISCUSSION

Multiple variance analysis results regarding the effect of the wood type, joining technique, and adhesive type on diagonal tensile strength are given in Table 3. The difference between diagonal tensile strengths of the wood type, adhesive type, and joining techniques were found to be statistically significant (a=0.05). Duncan test was applied to determine which differences between conditions were significant. Diagonal tensile strength averages (N/mm^2) of wood type, adhesive type, and joining techniques are given in Table 4.

According to the wood type, the highest diagonal tensile strength was found in the European oak (0,6951 N/mm^2), and the lowest has been found in the Scotch Pine (0.5083 N/mm^2). According to the joining technique, the highest diagonal tensile strength was found at 78° (0.7465 N/mm^2), and the lowest has been found in the dowel joint (0.4349

N/mm^2). In terms of the adhesive type, the highest diagonal tensile strength was found with PVAc (0.8277 N/mm^2), and the lowest was found with D-VTKA (0.4176 N/mm^2).

Average values of the diagonal tensile strength according to the mutual interactions of the wood type, adhesive type and joining techniques are given in Table 5.

Table 3. Multiple Variance Analysis Results Regarding the Effect of the Wood Type, Joining Technique and Adhesive type on Diagonal Tensile Strength

Variance Source	Degree of freedom	Sum of squares	Average of squares	F Value	P < 0,05
Wood Type (A)	2	0.963	0.481	95.0677	0,0000
Adhesive Type (B)	1	6.054	6.054	1195.5063	0,0000
A x B	2	0.367	0.183	36.2288	0,0000
Joining Technique (C)	5	1.260	0.252	49.7501	0,0000
A x C	10	0.297	0.030	5.8654	0,0000
B x C	5	1.043	0.209	41.1946	0,0000
A x B x C	10	0.137	0.014	2.7002	0.0054
Error	108	0.547	0.005		
Total	143	10.667			

Factor A: Wood Type (Oriental Beech, European oak, Scotch pine), Factor B: Adhesive Type (PVAc, Desmodur VTKA),
Factor C: Joining Technique (Dovetail 75°,78°,81°,84° Joint Dowel, Mortise and tenon joint)"

Table 4. Diagonal Tensile Strength Averages (N/mm^2) of Wood Type, Adhesive Type and Joining Techniques.

Wood Type*	X	HG
Oriental beech (B)	0.6644	B
European oak (O)	0.6951	A
Scotch pine (S)	0.5083	C
Joining Technique**		
75° (I)	0.6587	B
78° (II)	0.7465	A
81° (III)	0.6443	B
84° (IV)	0.6177	B
Dowel (V)	0.4349	C
Mortise and tenon (VI)	0.6335	B
Adhesive type***		
PVAc (P)	0.8277	A
D-VTKA (D)	0.4176	B

*LSD: 0.02853, **LSD: 0.04035, ***LSD: 0.02330,
X: arithmetic average, HG: Homogeneity Groups

In terms of wood type and joining technique, the highest diagonal tensile strength was found for B+II (0.8080 N/mm^2), while the lowest was found for S+V (0.3747 N/mm^2). In terms of wood and adhesive type, the highest diagonal tensile strength was found for O+PVA (0,9507 N/mm^2), and the lowest was found for S+D-VTKA (0.3722

N/mm^2). In terms of joining technique and adhesive type, the highest diagonal tensile strength was found for II+PVAc (0.9534 N/mm^2), while the lowest was found for V+D-VTKA (0.3485 N/mm^2).

Table 5. Diagonal Tensile Strength Averages According to the Mutual Interactions of the Wood Type, Adhesive Type and Joining Techniques (N/mm^2)

Wood Type + Joining Technique*	X	HG
B+I	0.7903	A
B+II	0.8080	A
B+III	0.6831	B
B+IV	0.6279	B
B+V	0.4045	DE
B+VI	0.6727	B
O+I	0.6966	B
O+II	0.7828	A
O+III	0.7734	A
O+IV	0.7004	B
O+V	0.5255	C
O+VI	0.6919	B
S+I	0.4716	CD
S+II	0.6664	B
S+III	0.4765	CD
S+IV	0.5250	C
S+V	0.3747	E
S+VI	0.5358	C
Wood Type + Adhesive Type**		
B+P	0.8878	B
B+D	0.4410	D
O+P	0.9507	A
O+D	0.4395	D
S+P	0.6445	C
S+D	0.3722	E
Joining Technique+ Adhesive Type ***		
I+P	0.7843	B
I+D	0.5332	C
II+P	0.9534	A
II+D	0.5780	C
III+P	0.9402	A
III+D	0.3485	E
IV+P	0.9149	A
IV+D	0.2821	F
V+P	0.5376	C
V+D	0.3322	EF
VI+P	0.8356	B
VI+D	0.4313	D
*LSD: 0,06989, **LSD: 0.04035, ***LSD: 0.05706		

Table 6. Diagonal Tensile Strength Duncan Test Results

Process Type	X	HG*	Process Type	X	HG*
O+P+II	1.184	A	B+D+II	0.5698	HI
O+P+IV	1.095	AB	O+D+I	0.5193	IJ
B+P+II	1.011	BC	S+P+I	0.5182	IJ
B+P+IV	0.9837	CD	B+P+V	0.4870	IJK
B+P+III	0.9768	CD	S+P+V	0.4807	IJK
O+P+III	0.9765	CD	O+D+VI	0.4550	JKL
B+P+I	0.9605	CD	B+D+VI	0.4375	JKL
O+P+VI	0.9288	CD	S+D+I	0.4250	JKLM
B+P+VI	0.9080	CD	O+D+V	0.4060	JKLMN
O+P+I	0.8740	DE	S+D+VI	0.4015	KLMN
S+P+IV	0.7810	EF	B+D+III	0.3895	KLMN
S+P+II	0.7575	FG	O+D+III	0.3623	LMNO
S+P+VI	0.6700	GH	B+D+V	0.3220	MNO
S+P+III	0.6593	GH	O+D+IV	0.3052	NO
B+D+I	0.6555	GH	S+D+III	0.2938	NO
O+P+V	0.6450	H	B+D+IV	0.2720	O
O+D+II	0.5890	HI	S+D+IV	0.2690	O
S+D+II	0.5752	HI	S+D+V	0.2687	O

*LSD: 0.09883

In terms of wood type, joining technique, and adhesive type, the highest diagonal tensile strength was found for O+P+II (1.184 N/mm^2), and the lowest was found for S+D+V (0.2687 N/mm^2). The graph is shown in Fig. 6.

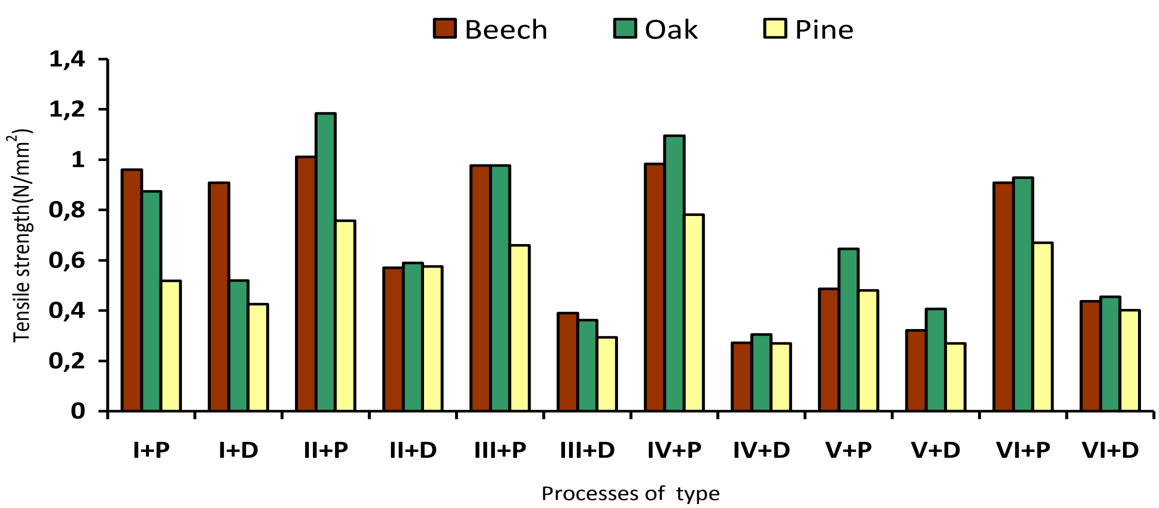

Fig. 6. Tensile strength according to wood type, joining technique and adhesive type

CONCLUSIONS

With respect to the type of wood, the highest diagonal tensile strength was found for European oak (0.6951 N/mm^2) and lowest in Scotch pine. According to this, the tensile strength of European oak was 4% more than Oriental beech and 27% more than Scotch pine. This may be due to the different textural structure of oak (medullary rays, curvature of fibers) which transmits force in a lower range. With respect to joining technique, diagonal tensile strength was highest for 78º dovetail joint (0.7465 N/mm^2), and lowest for dowel joint. The diagonal tensile strength of 78º dovetail joining was 12% more than 75°' dovetail angle, and 12% more than mortise and tenon joint, 14% more than 81, 17% more than 84° angle, and 42% more than dowel joint. This finding may be the results of greater attaching surface in teeth which are cut with 78° angle. Hence, the calculated surface area was found to be 2820.21 mm^2 at 78°. With respect to adhesive type, the tensile strength was found as (0.8277 N/mm^2), in polyvinylacetate adhesive, and (0.4176 N/mm^2) in polyurethane (D-VTKA) adhesive. According to this, the diagonal tensile strength of PVAc adhesive was 50% more than with respect to polyurethane D-VTKA adhesive. It can be inferred that most suitable adhesive is PVAc in the adhesion of the rail to leg joints that was made from massive wood material.

With respect to type of wood and joining technique, the highest diagonal tensile strength was found in the Oriental beech at + 78º (0.8080 N/mm^2), and the lowest in the Scotch pine+dowel (0.3747 N/mm^2). With respect to type of wood and adhesive interaction, the highest diagonal tensile strength was found in Oak+PVAc (0.9507 N/mm^2), and the lowest in Scotch pine + D-VTKA (0.3722 N/mm^2). With respect to joining technique and adhesive type, the highest diagonal tensile strength was found in 78º + PVAc (0.9534 N/mm^2), and lowest in dowel + D-VTKA (0.3485 N/mm^2). With respect to type of wood, joining technique and adhesive, the highest diagonal tensile strength was found in European oak + PVAc + 78º (1.184 N/mm^2), and the lowest in Scotch pine + D-VTKA + Dowel (0.2687 N/mm^2). According to this, it can be said that adhesive is primarily effective in joining, and respectively the type of joining and wood type are also important. Also, it can be said that the best diagonal tensile strength is obtained in the wood types that are fastened by PVAc adhesive at 78º with dovetail joint. Accordingly, in terms of diagonal tensile strength, it has been found important to use 78 º tooth angle in the dovetail joint and PVAc adhesive, which will be applied in the front leg-to-rail joint manufacturing for chair, armchair, and similar furniture that will be manufactured from massive wood.

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