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Bending Strength of Screwed Corner Joints with Different Materials

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ABSTRACT

Tests were carried out in order to determine the bending strength with compression and tension force with and without glue in addition to screws on furniture corner joints in a construction case. The specimens were prepared with particleboard and medium density fiberboard (MDF) surfaced with a synthetic resin sheet. In the connection, two types of screws which have dimensions of 4/50 mm and 5/60 mm were used. For the glued joints, polyurethane Desmodur-VTKA adhesive was used. As a result of these tests it has been determined that the joints with glue are better than the ones without glue and the strength of fiberboard is better than particleboard.

Keywords: Bending strength, compression test, tension test, particleboard, wood testing, screws.

1. INTRODUCTION

As the world population increases, economic conditions are becoming more difficult and life styles and human habits are changing. Life styles will affect furniture. Economic conditions change furniture styles as well. Because of the limited source of wood a lot of research has been conducted on the new type of particleboard and medium density fiberboard with synthetic resin sheet.

Especially at the beginning of the 1950' s, polyurethane (Desmodur-VTKA) adhesive was developed by the solid wood industry. In general for furniture products, three essential construction methods were used. Furniture was built by the case or frame method or by a combination of the two, the complex method. The case method means that the elements of furniture were plates. In the frame method, the elements of furniture were rods instead of plates. For an efficient design of the case method the furniture constructed using screws with and without glue requires specific design information on the bending strength of corner joints. Several investigations have been made on the corner joints that have yielded data on this design.

Hill and Eckelman [1] carried out a research project in order to determine the flexibility and bending strength of T type of mortise and tenon joints. Test results indicated that as joint size was increased the average ultimate strength of the joint also increased. Eckelman [2] tested seven different types of commercially available screws which obtained withdrawal resistance from 12 mm thick particleboard specimens. The results of the test indicated that there were practically no differences between the holding strengths of these screws. Zhang and Eckelman [3] carried out research on the bending resistance of single-pin dowel joints in particleboard. Test results indicated that the bending moment resistance of the single dowel corner joints increased significantly either as the dowel diameter increased from 6.4 mm to 19 mm or as the depth of the dowel embedment in the face member increased from 6.4 mm to 15.9 mm. Zhang and Eckelman [4] carried out the bending strength on 171, 229, 279 and 356 mm wide specimens that were constructed with 2 to 5 dowels in order to evaluate the ultimate bending strength of multi-dowel joints and optimum dowel spacings. Test results indicated that the maximum strength per dowel was obtained when dowels were spaced at least 76 mm apart. Results also indicated differences in strength between joints under tension and compression. Eckelman and Lin [5] carried out a research program in order to determine the bending strength of corner joints constructed with injection molded splines. Results indicated that high-strength

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joints can be formed by this process, but that the strength of the joints is highly dependent on the configuration of the spline.

Efe [6] tested different woods (scotch pine, oriental beech and oak) using different screw-nuts (through bolt with dowel nut) in pull-out tests. It was observed that the resistance strength of a screw-nut fixture increased as the screw-nut length increased, and decreased as screw-nut diameters increased. Also the withdrawal strength of the screw was affected by the thread height and distance between the threads. Efe and Kasal [7] worked on the case construction with and without glue corner joints under tension. The results were compared. Screwed joints gave better strength than the glued joints with a fiberboard.

Recently studies have been done on the applications of the fracture mechanics in timber joints. Daudeville et. al. [8] carried out a Finite Element method in the framework of Lineer Elastic Fracture Mechanics. The comparison between the experimental and numerical results showed that the main parameter of fracture mechanics was the critical energy release rate in mode I (G_{Ic}). This parameter must be considered to improve the design codes. Jansen et. al. [9] again applied fracture mechanics to the jointed timber parts. The critical energy release rate G_f (G_{Ic}) and shear strengths were calculated along the bond line. Similar fracture energy studies were done on concrete with compression tests by Barr et al [10].

In this study, maximum resistance strengths were compared for the case type corner joints which were made of particleboard and medium density fiberboard with different lengths and screws diameters. These screws were used with and without glue under a static tension and a compression load.

2. TEST MATERIALS

The specimens were prepared with particleboard and a medium density fiberboard surfaced with a synthetic resin sheet. The thickness of all the specimens were chosen as 18 mm. The specimens were produced according to the Turkish standards TS 64 (11) and TS 1770 (12) which are similar to the International Standard Organization ISO-767/1975. The glue (polyurethane) of approximately 200±10 gr/m^2 was used for each joint in the specimens. After the application, specimens were pressed together for approximately 1.5 hours at 20^{0}C temperature.

Polyurethane glue has only one component (active glue) which has a high resistance to water and humidity. This glue is excellent for wood, metal, polyester, stone, ceramic, PVC (polyvinyl chloride) and other plastics. It is especially suitable for marine structures and the external face of buildings. The cohessive strength of polyurethane glue is higher than the bonding strength. Glue thickness varied between 0.05 and 0.15 mm during bonding.

Philips head screws which are commonly used for composite plates, were used in the tests. Dimensions of the screws were 4/50 and 5/60 mm. The screws' material can be steel, aluminium, brass, copper bronze and cadminium. In this test steel screws (sheet metal) were used. The spiral effect of the screws gave a higher strength than the smooth surfaced nails.

3. TEST SPECIMENS AND EXPERIMENTS

To study the bending strength of screwed corner joints with different materials, tests were conducted at Gazi University, Ankara, Turkey. The test specimens are shown in Figure1. In preparing the specimens, full size sheets of particleboard and medium density fiberboard which had the dimensions 2.1×2.8 m were used. Each specimen had two plates named *F* and *B*. Dimensions of the face members (*F*) were 270×150 mm, dimensions of the butt members (*B*) were 270×132 mm. For glued joints, two plates were combined to each other with glue and 3 screws. A 3 mm diameter pilot hole was drilled before using the screw. For the joints without glue, only 3 screws were used. Screws were drilled to the center of the thickness of butt members. In these tests, two joint type connections with 10 specimens each were tested on two different boards, two different screws and two different loadings. The number of total tests was 2×2×2×2×10=160. Before the experiments, in order to eliminate moisture content variations, specimens were kept in a curing room for one month. The room temperature was 20±2^{0}C and the relative humidity was 65%.

It was observed that the resistance strength of furniture is related to the member materials and joints. As a definition the compression tests are described as the closing of joint agle in Figure 2a and tension tests are described as the opening of joint angle in Figure 2b.

4. ANALYSIS

Test specimens were tested at a 30 kN capacity Seidner bending frame with a 2 mm/min stroke rate under static loading. The tests methods are shown in Figure 2. Under the diagonal compression at the centre of the joint there is an external bending moment.

$$M_x=Pe, \quad e=P(L+0.5t\sqrt{2}) \qquad (1)$$

where, M_x=calculated bending moment at the center of the joint, P=measured ultimate axial load, e=eccentricity of load, and, L=lever arm in the horizontal direction, t=thickness of the butt elements were 18 mm. From the geometry (Figure 2), L is found as 80.6 mm for compression and as 93.3 mm for tension tests. Resistance of the joints with and without glued screws were considered. In calculating at the surface, the effect of internal friction between the surfaces, dowel action of screws, and shear effects were ignored.

During the experimental process, glued joints with screws in L type corner joint elements were under the normal stress level. The external bending moment according to the center of the joints was given as eq.(1).

Under combined moment and axial force, normal stresses were found as follows:

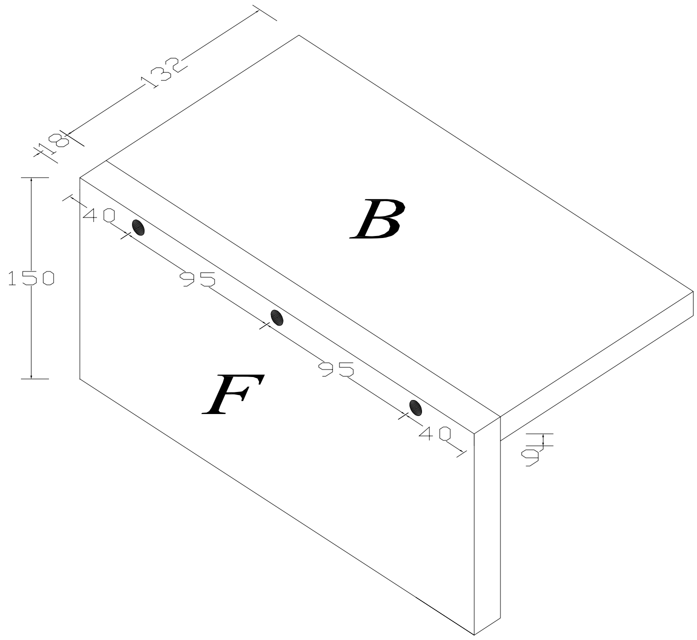


Figure 1. Test specimens

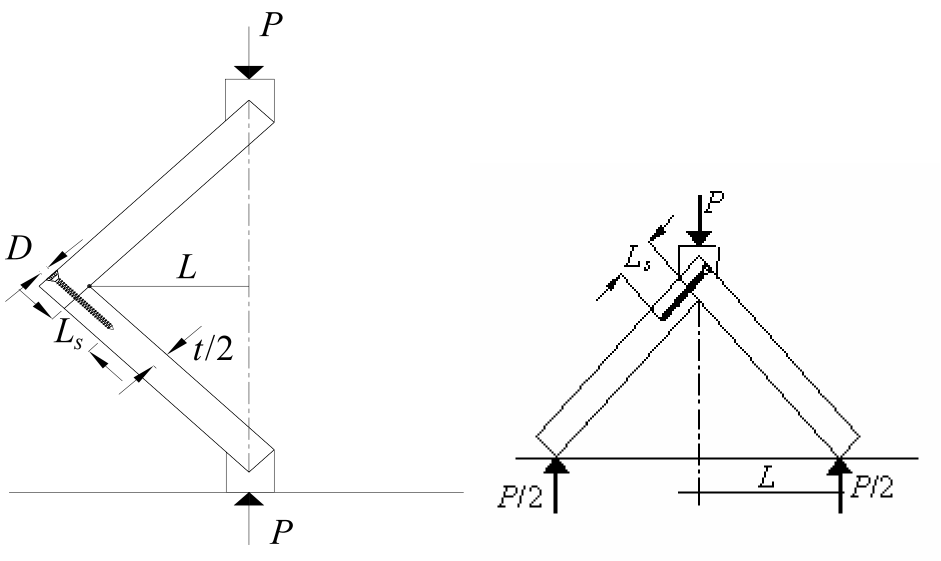


Figure 2. Methods of loading the joints in compression (a), and in tension (b)

$$\sigma_{1,2} = \frac{P}{A}(\cos\alpha \pm \frac{6e}{t}) \quad (2)$$

In this formula the effect of shear force was ignored. A is the area of the connection, $A=bt$, $\alpha=45^0$. In eq.(2), the subscript 1 stands for the compression face of the joint for which (+) sign of the second term is considered. In the same equation the subcript 2 stands for tension face of the joint and for which (-) sign of the second term of the eq.(29 is used. For the contribution of screws, σ_s is calculated by

$$\sigma_s = \frac{P_s \cos 45^0}{n\pi D L_s} \quad (3)$$

where, n=number of the screws (3), P_s=loads taken by screws, D=diameter of screws, L_s=penetration of the threaded portion of screw (Fig.2). In eq.(3) stresses were determined for the joints without glue. Total stress is figured as

$$\sigma = \sigma_g + \sigma_s \quad (4)$$

where, σ_g=contribution of glue, σ= total stress at the joint. The screw was penetrated at the middle of the butt member, that is why moment effect will become zero in the eq.(3). Compression test results were given for the particleboard and medium density fiberboard in Table 1. For tension tests, the equations in which $P/2$ is substituted for P in eq.(1, 2 and 3). Tension test results are given in Table 2 for the same material and joint connections. The mean values of the test results under tension and compression were given in the bottom line of Table 1 and Table 2 with the standard deviations (*SD*).

Table 1. Measured ultimate axial load as a Newton (N) under the compression

Specimen No	Fiberboard				Particleboard			
	With glue (*P*)		Without glue (P_s)		With glue(*P*)		Without glue (P_s)	
	4/50	5/60	4/50	5/60	4/50	5/60	4/50	5/60
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	1180	1190	520	910	650	880	420	730
2	920	1200	410	780	730	920	480	650
3	1000	1480	450	810	650	900	500	810
4	1120	1530	680	970	690	850	560	800
5	1150	1520	550	970	580	750	510	680
6	920	1500	500	820	680	850	530	800
7	1150	1420	450	870	810	910	480	650
8	1180	1150	550	900	820	600	520	620
9	1100	1100	700	700	800	800	480	620
10	1110	1330	650	950	620	840	520	700
Mean (N)	1083	1342	546	868	703	830	500	706
SD (N)	100	169	101	89	84	96	88	75

Table 2. Measured ultimate axial load as a Newton (N) under the tension

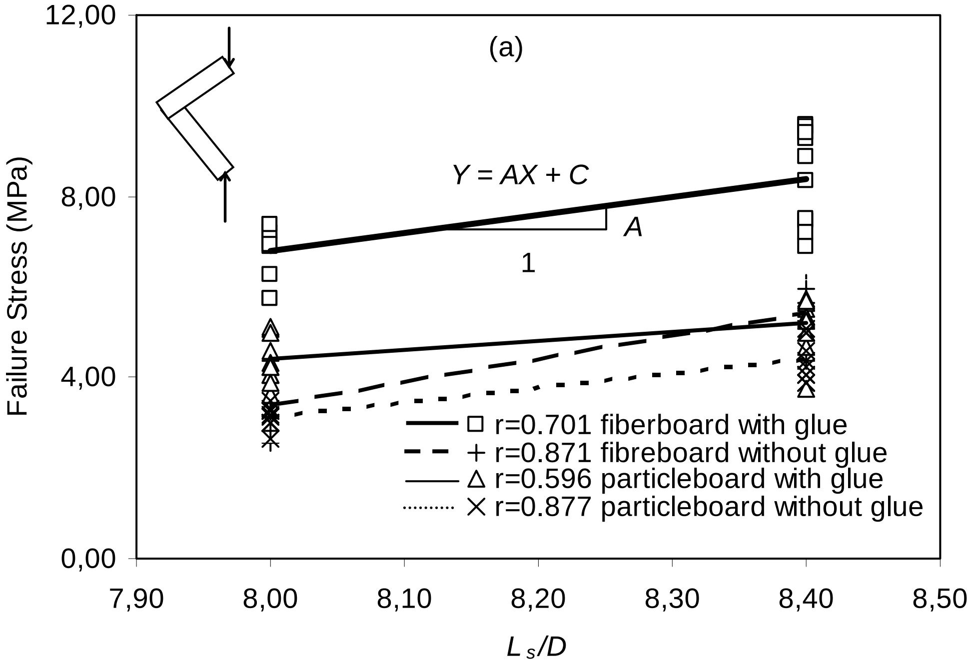
Specimen No	Fiberboard				Particleboard			
	With glue (*P*)		Without glue (P_s)		With glue(*P*)		Without glue (P_s)	
	4/50	5/60	4/50	5/60	4/50	5/60	4/50	5/60
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	1650	2250	970	1810	1250	1600	1080	1700
2	1750	2500	1100	1480	1100	1900	980	1420
3	1480	2350	900	1700	1680	1300	1060	1450
4	1750	2550	920	1690	1200	1790	950	1810
5	1650	2320	950	1600	1550	1680	1230	1480
6	1350	2280	1250	1600	1500	1650	1280	1380
7	1330	2300	950	1600	1600	1500	1080	1600
8	1380	2620	1100	2000	1630	1920	1050	1600
9	1650	2450	1050	1420	1300	1500	1010	1700
10	1500	2620	1250	1600	1330	1400	980	1350
Mean (N)	1549	2424	1044	1650	1414	1624	1070	1549
SD (N)	162	142	129	165	203	206	108	156

The relation between the bending strength and ratio of depth of screw embedment in the butt members to diameter of screw, for this limited data, was assumed to be a linear function.

$$Y=AX+C \qquad (5)$$

Where X=ratio of penetration lengths of screws to diameter, Y=failure stress given in eq.(2), A=slope of the regression line, C=interception of the regression line at the vertical axis in Y. The compression and tension failure stresses are given in Fig.3a and in Fig.3b respectively for two points.

Unfortunately in these tests only two different screw sizes of 4/50 mm and 5/60 mm are used. It is better to have at least three different sizes of screws for generalization.



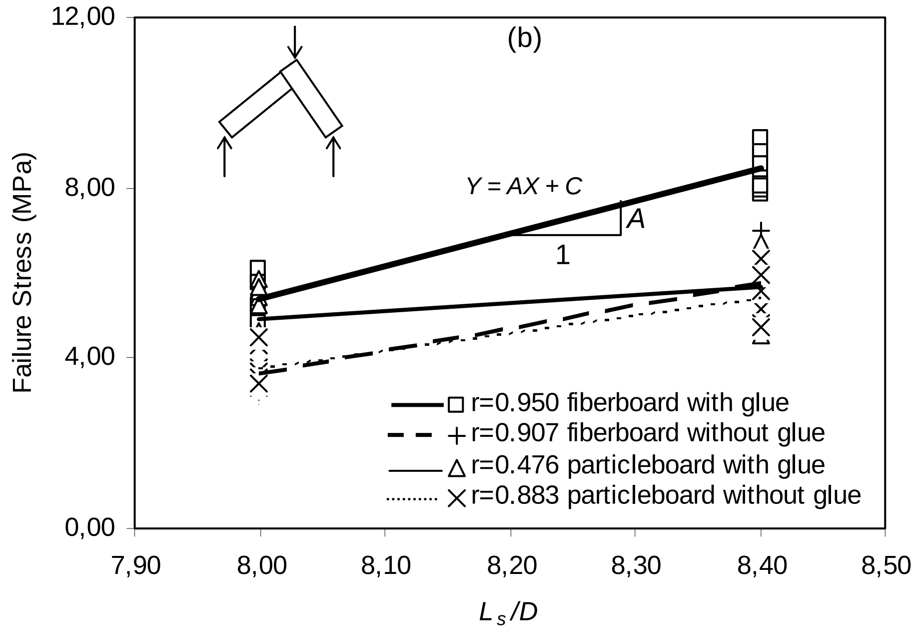


Figure 3. Test results of joints a)in compression, b)in tension

5. RESULTS

Compression and tension test data results were given in Table 3 using least square methods in linear regression. In this table slope of regression (*A*), interception of at the vertical axis (*C*), with correlation coefficients (*r*) were given for with and without glue and for particleboards and fiberboards. Best correlation was seen for tests results of fiberboard with glue under tension (*r*=0.950).

Table 3. Coefficient of linear regression

Loading	Material	Glue	*A*	*C*	*r*
(1)	(2)	(3)	(4)	(5)	(6)
Compression	Fiberboard	with	4.05	-25.63	0.701
		without	5.04	-36.87	0.871
	Particleboard	with	1.99	-11.49	0.596
		without	3.22	-22.65	0.877
Tension	Fiberboard	with	7.64	-55.68	0.950
		without	5.29	-38.66	0.907
	Particleboard	with	1.83	-9.72	0.476
		without	4.18	-29.71	0.883

Tension strength of glue was affected by the material type, screw and loading. To determine the contribution of glue average values of load was subsituted in the formula, $P_g=P-P_s$. P_g was contribution of glue, *P* was measured ultimate load with glue, P_s was contribution of screw, obtained without glue from Table 1,2. From the tests results tension strength of glue eq. (2) was found maximum for fiberboard under the compression with screw dimension 4/50 as a 3.36 MPa. Average values of test results were used for this calculation. Minimum effect of glue was obtained under the tension for particleboard material and screw dimension 5/60 mm as a 0.27 MPa as seen in Table 4.

Table 4. Tension strength of glue

Loading	Material	Screw mm	*P*(with) N	P_s(without) N	P_g N	Mom. Nmm	σ_g MPa
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Compression	Fiberboard	4/50	1083	546	537	50117	3.36
		5/6	1342	868	474	44237	2.97
	Particleboard	4/50	703	500	203	18946	1.27
		5/60	830	706	124	11573	0.78
Tension	Fiberboard	4/50	1549	1044	505	26772	1.80
		5/60	2424	1650	774	41033	2.76
	Particleboard	4/50	1414	1070	344	18237	1.23
		5/60	1624	1549	75	3976	0.27

One type of mode of failure was the opening failure that occurred under the normal forces. Opening failure starts at the edge of the joint and then propagates towards to the top of the joint with increasing load for glued joints. As the glue looses its strength, the screws start to take the load. For some of the glued joints of the particleboards, some board pieces crushed and came out under tension or compression. For the fiberboards especially with 5/60 mm screws some cracks occur in the transverse direction at the edge of board under the opening mode. In the case of joints without glue, opening starts at the edge of joint and ends at the top of the joint with increasing load. After reaching ultimate capacity of joint, load bearing capacity of joints were ended.

6. DISCUSSION and CONCLUSION

Mechanical properties of the case type corner screwed joints with and without glue are compared for particleborad and medium density fiberboard under tension and compression. The effect of the screws, materials and glue are seen in the tests results given in Figs.3a for compression and Fig.3b for tension.

Glued joints give better performance than the screwed joints as expected. The failure loads of the fiberboard joints was higher than the particleboard joints by 54% with screw 4/50, by 62% with screw 5/60 under compression by 10% with screw 4/50, by 49% with screw 5/60 under tension with glue. This higher strength can be explained by the following reasons. The structural properties of material adhesion and screw holding capacity affect the bending strength, specific gravity of fiberboard is higher than the particleboard. Adhesion of the fiberboard is stronger than the particleboard; the touching point in rough surface particleboard joint is weak; the screw holding capacity is higher in fiberboard than in particleboard.

The 5/60 screws give higher failure loads than the 4/50 mm screws 24% high under compression 56% high under tension for fiberboard with glue as in seen in Table 1-2 and 4. Diameters and lengths of screws affect the strength. As screw diameter and length increases, screw withdrawal resistance increases. According to the test results in Table 1 and 4, screw with glue gives higher load in fiberboard material. Glue gives a load increase for particleboard under compression, which was found out 41% for the 4/50 screws and 18% for the 5/60 screws.

The measured ultimate axial loads under the tension were found as two times of the ultimate axial loads under the compression. The reason for this difference is, the ultimate moment at joint in compression is twice the ultimate moment of tension under the same load.

In these tests only two different types of screw size were used. For future studies it is better to have at least three or more screw diameters or lengths.

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