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Effect of Some Factors on the Strength of Furniture Corner Joints Constructed with Wood Biscuits*

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Abstract: This study was carried out to evaluate the bending moment resistance and stiffness of case-type furniture corner joints constructed with wood biscuits, and to determine the effects on these joints of some factors including the spacing between wood biscuit hole centers, the distance from the center of the biscuit hole to the corresponding outside edge of the board material, the method of loading, the type of composite board, and the gluing technique. The results indicated that corner joint strength comes mainly from the edge gluing of the face and butt member and not from the glued biscuits. Particleboard (PB) glued and unglued edge corner joints were stronger than similar joints constructed with MDF (medium density fiberboard). Glued edge MDF corner joints were stiffer than similar joints constructed with PB. Spacing between biscuits of 10, 12.5 and 15 cm on-center in multiple-biscuit corner joints made only small differences in total strength in both tension and compression tests. Therefore, in case-type furniture manufacturing, using 15 cm on-center biscuit spacing instead of 10 cm seems much better in terms of saving time and biscuit joints. Unglued and glued edge joints had greater strength when the distance was 5 cm between the biscuit hole and the corresponding outside edge of the specimen than when it was 6.5 or 7.5 cm with 12.5 cm on-center biscuit spacing. However, in industry most case-type furniture designs have a fixed end instead of a free end joints, and so using a 6.5 or 7.5 cm end distance instead of 5 cm may not make any difference.

Key Words: Wood biscuits, furniture, corner joints

Odun Bisküvili Köşe Birleştirme Uygulanmış Mobilyanın Direnci Üzerine Bazı Faktörlerin Etkisi

Özet: Bu çalışma, ahşap bisküvi bağlayıcıları ile tasarlanmış mobilya köşe birleştirmelerin direnç ve eğilme momenti üzerine bazı faktörlerin (bisküvi delik merkezleri arasındaki mesafe, bisküvi deliği merkezleri ile levhaların dış kenarları arasındaki mesafe, yükleme metodu, levha tipi ve yapıştırma tekniği gibi) etkilerini değerlendirmek amacıyla gerçekleştirilmiştir. Köşe birleştirmelerin mukavemetlerinin genel olarak yapıştırılmış bisküviden değil yüz ve kenar ile birleştirme elemanlarının bütün olarak yapıştırılmasından kaynaklandığı belirlenmiştir. Yonga levhalardan yapılan tutkallı veya tutkalsız köşe birleştirme dirençlerinin MDF lerden daha yüksek olduğu, kenarları bütün olarak yapıştırılmış birleştirmelerde MDF lerin yonga levhalardan daha dayanıklı olduğu saptanmıştır. Çoklu bisküvili köşe birleştirmelerde, bisküvi merkezleri arasındaki mesafenin artışı (10, 12.5 ve 15 cm) basınç ve çekme direnci değerlerini az miktarda yükseltmiştir. Sonuç olarak kabin tipi mobilya üretiminde dayanıklılığın öncelikli olduğu konstrüksiyonlarda; bisküvi merkezleri arasındaki mesafenin 10 cm yerine 15 cm olarak uygulanmasının bisküvi sayısını ve dolaysıyla işlem sayısını azaltarak kapasiteyi arttırması bakımından daha uygun olacağı belirtilebilir. Sadece bisküvi boşluklarının ve bütün kenarın tutkallandığı köşe birleştirmelerde; bisküvi boşluk merkezleri ile dış kenar arasındaki mesafenin 5 cm olarak uygulanması mukavemeti 6.5 veya 7.5 cm uygulanmalarına oranla artırmıştır. Ancak endüstriyel uygulamalarda kabin tipi mobilya tasarımlarında genellikle tutkalsız (demonte) birleştirme yerine tutkallı birleştirmeler uygulanmaktadır. Bu nedenle bisküvi boşluğu ile dış kenar arasındaki mesafenin 5 cm yerine 6.5 veya 7.5 cm uygulanmasının mukavemet yönünden herhangi bir farklılık yapmayacağı sonucuna varılmıştır.

Anahtar Sözcükler: Odun bisküviler, mobilya, köşe birleştirmeler

Introduction

Although joints of wood biscuit are widely used in the construction of furniture cases, there is no information available that can be used in the design of multi-fastener joints. Most available information is about dowel joints. Also, limited information is available on the bending strength of corner joints. However, those furniture engineers who design cases on rational bases must have

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specific quantitative information concerning the bending strength of multi-fastener joints.

Even though joint design is the one of the most important steps in furniture design, still there is very little information known quantitatively. According to Eckelman (2003), joints are generally the weakest part of a piece of furniture and they are the primary cause of failure. Eckelman (1971) reported that the strength and stiffness of joints used in furniture construction normally determine the furniture's strength and rigidity. Eckelman and Munz (1987) have also stated that most of joints used in furniture construction are in fact semi-rigid because under a bending load the joint rotates slightly.

Nowadays, for general woodworking there are 3 basic standard sizes of biscuits: a number 0 biscuit is 15 mm wide and 45 mm long, a number 10 biscuit is 19 mm wide and 53 mm long; and a number 20 biscuit is 23 mm wide and 60 mm long. Biscuits thickness is 3.8 mm. Although 3 size biscuits are available, the common size used is number 20 (Foster, 1996). Biscuit joints, also called plate joints, are made from solid beech and are slightly compressed so that the plates can absorb moisture from water-based glue, causing them to swell in the slots for a tight fit and strong bond (Speas, 1994).

This study was performed to provide background information concerning the bending strength behavior of biscuit joints constructed with medium density fiberboard (MDF) and particleboard (PB), as well as to provide background information about the rational design of multi-fastener L-type corner joints. The objectives of this study were as follows: (1) to evaluate the bending moment resistance and stiffness of furniture corner joints designed with biscuit fasteners, (2) to determine the effects on furniture corner joints connected with biscuit fasteners of the following factors: the spacing between biscuit hole centers, the distance from the center of the biscuit hole to the corresponding outside edge of the board type, the method of loading, the type of composite board, and the gluing technique.

Materials and Methods

Description of specimens

The configuration of specimens used in the study is shown in Figure 1. In this study, Zhang and Eckelman's (1993) work was used for the preparation of samples and testing. Each L-shaped specimen consisted of 2 principal structural members, a face and butt member. In preparing the specimens, full size 19 mm thick sheets of PB and MDF (1.22 by 2.44 m) were first cut in the middle into 2 pieces. From the 1.22 by 1.22 m sheets of PB and MDF face and butt member strips were cut using a table saw. These strips were subsequently cut into 72 PB and 72 MDF face members, which were 22.5, 25.5, 27.5, 30, 35 and 40 cm in length by 16 cm in width. A similar set of butt members, which differed only in width (14 cm), were prepared. The widths of the face and butt members were chosen so that when the 2 parts were joined together along the length of the specimens, a symmetrical joint cross-section resulted. Specimens were constructed with PB, 36 of which were tested in compression and 36 of which were tested in tension. Specimens were also constructed with MDF; 36 were tested in compression and 36 in tension. In all, 144 specimens were prepared. The lengths of specimens, the number of specimens used, the method of gluing, and the number of biscuits used in each size of specimen are shown in Tables 1 and 2.

Solid beech biscuits were used in this study. The number 20 biscuit was 24 mm by 60 mm. The portable biscuit joiner had a scale set on a proper number in order to cut a slot in the center of the 19 mm thick board. This set was used to make slots both on the face of the face member and the edge of the butt member. The slots for the biscuits were cut at a speed of 10,000 rpm using a

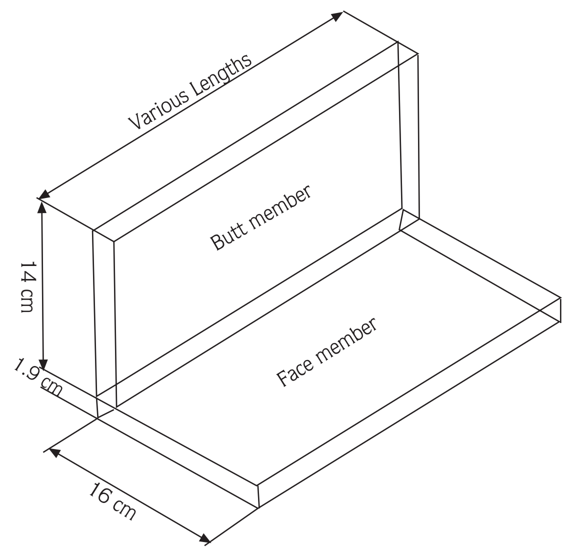

Figure 1. General configuration of the specimen used to evaluate the factors' effect on the corner joints and to determine joint strength.

Table 1. Description of the 2 biscuit specimens at 12.5 cm on the center used in evaluation of the edge distance effect (3 replicates each row).

Length of specimen (cm)	Material type*	Edge distance (cm)	Gluing method		Loading form	
			Unglued	Glued	Compression	Tension
22.5	PB	5	*		*	*
22.5	PB	5		*	*	*
22.5	MDF	5	*		*	*
22.5	MDF	5		*	*	*
25.5	PB	6.5	*		*	*
25.5	PB	6.5		*	*	*
25.5	MDF	6.5	*		*	*
25.5	MDF	6.5		*	*	*
27.5	PB	7.5	*		*	*
27.5	PB	7.5		*	*	*
27.5	MDF	7.5	*		*	*
27.5	MDF	7.5		*	*	*

*PB: Particleboard; MDF: medium density fiberboard

Table 2. Description of the 3 biscuit specimens used in evaluation of the space between the biscuit hole centers with a constant 5 cm end distance (3 replicates each row).

Length of specimen (cm)	Material type*	Space between biscuit hole centers (cm)	Gluing method		Loading form	
			Unglued	Glued	Compression	Tension
30	PB	10	*		*	*
30	PB	10		*	*	*
30	MDF	10	*		*	*
30	MDF	10		*	*	*
35	PB	12.5	*		*	*
35	PB	12.5		*	*	*
35	MDF	12.5	*		*	*
35	MDF	12.5		*	*	*
40	PB	15	*		*	*
40	PB	15		*	*	*
40	MDF	15	*		*	*
40	MDF	15		*	*	*

*PB: Particleboard; MDF: medium density fiberboard

portable plate (biscuit) joiner. A rapid feed rate was used in order to avoid charring the wall of the slots. Before assembling, the slots in the face and edge members were cleaned with compressed air to remove dust in order to promote good bonding of the pieces.

All specimens were glued with either 1) biscuits only, referred to as "unglued" or 2) whole edges and biscuits, referred to as "glued". All specimens were assembled with a polyvinyl acetate emulsion adhesive with 65% solids content. A double spread technique was used, in which adhesive was applied to both the walls of slots and the surfaces of the biscuits. The biscuits were first inserted into the face members to ensure that they were centered with in the slots. In the samples with glue only on the biscuit and biscuit hole, melted wax paraffin was applied to the mating surfaces of the face and butt members prior to gluing in order to prevent the face from adhering to the butt member. Another set of samples referred to as "glued" had adhesive applied to the biscuit, the biscuit hole, and face member. All specimens were clamped in a radial arm gluing machine with enough pressure to bring the joints tightly together. All specimens were allowed to cure for at least 1 week before testing.

Design of study

The strength of joints was characterized by the bending moment value at which the joint was destroyed. In compression and tension, the bending moments ($M = R * d$) were different from each other in terms of the relationship between the joint bending moments, M reaction against the applied load, R, and moment arm, d. Applied loads were converted to moment acting at the joint center per inch of joint width.

According to Rabiej et al. (1993), the rotation of the joint under the load can be calculated by this expression:

$L^2 = H^2 + R^2$ definitions of L, H, Ho and R are shown in Figure 2.

$R^2 = L^2 - H^2$

$\phi = \text{Sin}^{-1}\left(\frac{H}{L}\right)$

H = Ho – displacement

Rotation = $90 - 2 * \phi$

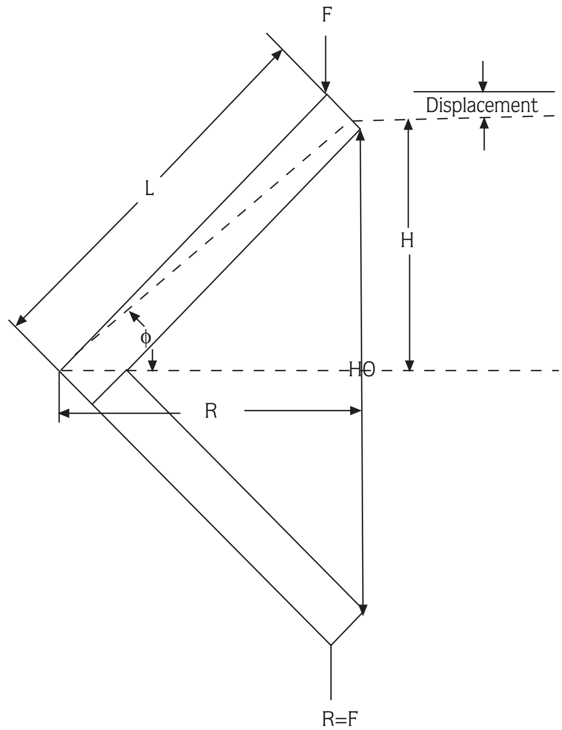

Figure 2. Method of calculation of the moment and rotation in compression.

Testing

All tests were performed on a Baldwin-Lima-Emery Universal Testing Machine. The L-type corner joints were loaded in compressive bending and tensile bending. In the case of the compression test, samples were placed between the movable head and the base of the testing machine so that the joints were forced to close. This action tends to reduce the angle formed by the members joined together (Figure 2). A linear variable differential transducer (LVDT) was placed between the movable head and the base of the testing machine in order to measure deflection. In the case of the tension test, each member was placed on rollers so that the joint was forced to open (Figure 3). This action tends to enlarge the angle formed by parts joined together.

A rate of loading of 0.64 cm minute-1 was used in all tests. In the tension test setup case, legs positioned horizontally on rollers on the bed of the testing machine so that the 2 joint members were free to move sideways when the joint was loaded. Steel bars were used to distribute the load uniformly along the length of the specimens. In the compression setup, the specimens were positioned in the testing machine so that loads were applied by the fixed crosshead to one leg of the specimen and to the other leg by the moving bed of the testing machine. The load line passed from outside the top edge through the outside bottom edge of the legs. Most of the specimens were longer than the load head of the testing machine. Therefore, a steel I-beam was attached to the head of the testing machine and loads were applied through it so that they were applied uniformly along the length of the joint (Zhang and Eckelman, 1993).

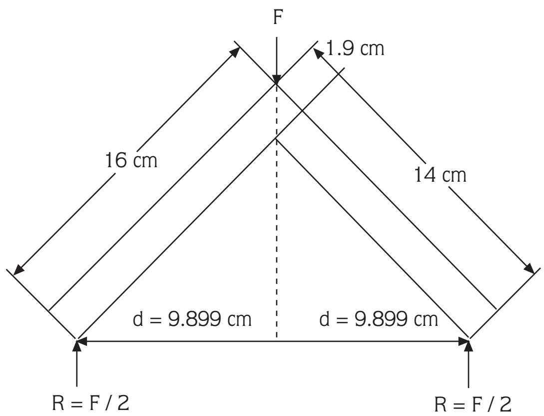

Figure 3. Cross-sectional measurements and loading form in the tension test.

Statistical Method

Statistical Analysis Software (SAS) has the facility to perform both stepwise regression analysis and correlation analysis. Stepwise regression in SAS is the most helpful method for choosing the best model, because it can give an insight into the relationships between independent and dependent variables. Stepwise addition regression is another statistical procedure; it includes only those parameters or variables that are statistically significant in the model (Draper and Smith, 1981). The SAS program was used to investigate the effects of type of loading, gluing technique, length of specimens, number of biscuits used, space between the biscuit hole centers, and end distance on the strength of corner joints constructed with biscuits.

In the model, a 95% confidence level was used for all variables. The dependent variable was the maximum bending moment strength. Independent variables were type of material (2 levels), gluing technique (2 levels), loading type (2 levels), space between the biscuit hole centers (3 levels), end distance (3 levels), length of specimen (6 levels) and number of biscuits used (2 levels).

Results and Discussion

Effect of material type and type of loading

The moisture content (MC) of the PB averaged 7.75%, specific gravity averaged 0.65 and density averaged 0.64 g cm^{-3}. The MC of MDF averaged 5.95%, specific gravity averaged 0.72 and density averaged 0.7 g cm^{-3}. The MC of biscuits averaged 4.92%.

Both glued and unglued edge MDF corner joints had slightly less strength when loaded in compression than when they were loaded in tension. According to Zhang and Eckelman (1993), the reason for this phenomena is that the bending strength of joints loaded in compression is presumably related to the internal bond strength of the board, whereas the bending strength of joints loaded in tension is presumably related to the surface tensile strength parallel to the plane of the board.

Average maximum strengths of the test specimens are given in Table 3. PB corner joints in both glued and unglued edge cases and with 2 loading types were stronger than MDF corner joints. In unglued edge joints, the percentage increase of PB over MDF was much greater than for glued edge joints (Table 4).

Effect of biscuit spacing and end distance

The results shown in Table 3 indicate that the ultimate bending strength of the corner joints may depend on the spacing between the biscuit hole centers, since as the this space increased from 10 cm to 15 cm, the strength of the corner joints slightly increased. Eckelman and Munz (1987) pointed out that the bending strength of doweled post and flatwise rail joints increased as the dowel spacing increased from 1 to 3 cm.

As shown in Table 3, in both tension and compression tests, the average maximum moment per meter of glued edge 22.5 cm PB and MDF specimens with 5 cm end distance was greater than that of 25.5 cm specimens with 6.5 cm end distance and 27.5 cm specimens with 7.5 cm end distance. However, most case-type furniture designs are based on the fixed instead of free end joints, and so using a 6.5 or 7.5 cm end distance instead of 5 cm may not make any difference.

In the tension test, when the end distance was 5 cm, all unglued edge joints had greater strength than when the end distances were 6.5 and 7.5 cm. On the other hand, in the compression test the result of the unglued edge joint showed that there was not a specific pattern in terms of end distance.

Effect of gluing techniques

Corner joint strength comes mainly from the edge gluing of face and butt members and not from the glued biscuits. PB glued edge corner joints were on average 95% and 123% stronger than PB unglued edge corner joints, respectively, in the tension and compression tests. Meanwhile, MDF glued edge corner joints were on average 187% and 287% stronger than MDF unglued edge corner joints, respectively, in the tension and compression tests. The biscuits serve to accurately align the face and butt members during assembly and clamping. They do not really contribute to the strength of the corner joints.

Stiffness of the corner joints

The applied load in compression bending was converted to a moment value and the deformations of the corner joints were converted to rotations. A continuous moment and rotation curve was generated for all joints in compression. The slope of the initial part of the curve indicates the stiffness.

Table 3. Results of 3 corner joints constructed with biscuits in tension and compression tests.

Joint type and length (cm)	Average maximum moment (N.m) in tension (SD)	Maximum moment in length (N.m)	Average maximum moment (N.m) in compression (SD)	Maximum moment in length (N.m)
PB glued edge				
40	94 (33)	5.88	98 (42)	6.10
35	78 (32)	5.54	91 (7)	6.55
30	73 (18)	6.10	67 (14)	5.54
27.5	56 (13)	5.09	64 (32)	5.76
25.5	54 (19)	5.42	60 (12)	5.99
22.5	58 (27)	6.44	55 (19)	6.10
PB unglued edge				
40	48 (32)	3.05	49 (12)	3.05
35	47 (6)	3.39	46 (14)	3.28
30	38 (21)	4.29	32 (8)	2.60
27.5	23 (9)	2.03	20 (7)	1.81
25.5	27 (10)	2.71	22 (6)	2.26
22.5	29 (16)	3.28	26 (3)	2.94
MDF glued edge				
40	77 (35)	4.86	74 (15)	4.63
35	73 (32)	5.20	71 (30)	5.09
30	72 (21)	5.99	62 (21)	5.20
27.5	55 (32)	4.97	40 (6)	3.62
25.5	50 (36)	4.97	47 (18)	4.75
22.5	57 (17)	6.33	43 (10)	4.86
MDF unglued edge				
40	27 (7)	1.70	21 (7)	1.36
35	26 (3)	1.92	18 (8)	1.24
30	23 (6)	1.92	15 (6)	1.24
27.5	20 (2)	1.81	14 (5)	1.24
25.5	17 (6)	1.70	8 (4)	1.92
22.5	21 (9)	2.26	11(4)	1.24

SD = Standard deviation, PB = Particleboard, MDF = Medium Density Fiberboard

Table 4. Tensile and compressive strength increases of PB joint over MDF joint in terms of percentages.

	Tensile strength (% increase)		Compressive strength (% increase)	
Joint Length (cm)	Glued Edge	Unglued Edge	Glued Edge	Unglued Edge
40	21.68	74.80	31.07	129.76
35	10.96	78.61	28.55	155.23
30	0.71	66.88	7.73	107.49
27.5	1.45	14.61	58.31	45.90
25.5	7.29	57.34	27.05	184.11
22.5	2.06	42.40	27.12	127.51

As shown in Table 5, glued edge corner joints were on average 168% and 283% stiffer than unglued edge corner joints when constructed from PB and MDF, respectively. Glued edge MDF corner joints were on average 11% stiffer than similar joints constructed with PB. The first reason for this is that MDF has greater density than PB; therefore, it has less void space but more mass to resist compression force. The second reason is that the void spaces of MDF are smaller than these of PB, limiting adhesive penetration.

Table 5. Stiffness of the corner joints in the compression test.

Joint length (cm)	Average stiffness of PB edge joints (N.m /degree)		Average stiffness of MDF edge joints (N.m /degree)	
	Glued edge	Unglued edge	Glued edge	Unglued edge
40	34	15	38	10
35	32	13	30	8
30	26	9	25	9
27.5	23	6	30	7
25.5	19	7	25	5
22.5	19	9	22	7

Type of Failure

Type of failure depended on the manner in which the joints were loaded, type of material and gluing techniques. For edge-glued MDF tested in compression, the edge of the face member split within its thickness and the split was continuous, parallel and very close to the glue line throughout the length of the specimens. In this type of failure, the glue line and biscuit maintained their integrity completely under the load.

In the case of PB glued edge samples in compression the face member is the weakest part of the joint connection. Failure occurred within the PB parallel to the glue line in the core but never within the glue line itself. The splitting as a result of failure was discontinuous and curvilinear within the PB core. This can be explained by the vertical density gradient of the PB and MDF. In PB core density is lower than the face density, and so core strength is lower than face strength. In the tension test, both with MDF and PB glued edge samples, butt members split inside the corner of the joints near the glue line. The shape of the failure was linearly continuous throughout the length of specimens.

The unglued edge specimens constructed with MDF and PB almost failed in similar ways when loaded in either tension or compression. There were 2 readily definable types of failure, which could be categorized as follows.

Type I: The biscuits withdrew from the butt member of the corner joints along with some core material attached to the biscuits. In PB constructed specimens the amount of attached core material was considerably more than in those constructed with MDF.

Type II: The biscuits withdrew from the butt member along with some core material attached to the biscuits and a small piece was fractured from the lower part of the biscuit.

Type I failure occurred in 94.4% of the specimens and Type II failure occurred in the other 5.6%. The butt member is the weakest part of the joint connection because biscuits always withdrew from the edge member with some core material. In the butt member, biscuit slots must be placed in the core of the board. Since the core of the board has lower density, the holding strength is less than that of the face of the board.

Statistical analysis of data

Space between biscuit hole centers, type of material and number of biscuit did not have a statistically significant effect on the strength of the corner joints at the 0.05 significance level. However, type of loading, gluing technique, length of specimen and end distance met the 0.05 significance level for entry into the model. The coefficient of determination, r^2, of the model was 0.8553. Stepwise regression selection also gave the contribution of the each variable in the population r^2. The contribution of loading type was 0.4861, the contribution of gluing technique was 0.2938, the contribution of the length of the specimen was 0.0671 and the contribution of end distance was 0.0082.

Maximum bending moment strength and type of material were highly correlated, because the correlation coefficient between them was approximately 0.7. Maximum bending moment strength of the corner joints and type of loading were also highly correlated, because the correlation coefficient for them was approximately 0.7. In addition, there was a correlation between maximum bending moment strength and gluing technique, since their correlation coefficient was 0.55. On the other hand, maximum bending moment strength had a very weak correlation with the other variables or there was no correlation at all. All variables left in the model are significant at the 0.05 level, in other words a 95% confidence level was used (see Table 6).

Comparison of biscuit with dowel joints

As shown in Table 7, the results of this study with particleboard were compared with those of similar studies with dowel joints reported by Eckelman (1970) and Guntekin (1997). Maximum bending moment values were divided by the length of the specimen to obtain maximum moment per inch values for comparison. Therefore, biscuit joints in both compression and tension bending tests were better than dowel joints.

Conclusion

The test results indicate that PB glued and unglued edge corner joints were stronger than similar joints constructed with MDF. The tensile strength increase in particleboard corner joints over MDF corner joints was on average 7.4% in the glued edge case and 55.8% in the unglued edge case. In the compression test, glued edge MDF corner joints were stiffer than similar joints constructed with PB. The unglued PB and MDF had very low stiffness and strength compared to edge glued face to butt corner joints.

The results also indicate that corner joint strength comes mainly from the gluing of face and butt members and not from the glued biscuits. All joints had slightly less strength when loaded in compression compared to tension except for PB glued joints, in which compressive strength was slightly greater than tensile strength. In case-type furniture manufacturing, using 15 cm center biscuit spacing instead of 10 cm seems much better in terms of saving time and biscuit joints. As the space between the biscuit hole centers increased from 10 to 15 cm, the ultimate bending moment strength of unglued edge corner joints slightly increased. In industry most case-type furniture designs have fixed end instead of free end joints, and so using a 6.5 or 7.5 cm end distance instead of 5 cm may not make any difference.

In general, for the glued edge specimens in compression tests, the face member of PB and MDF specimens appears to be the weakest part of the joint connection. In tension, however, butt members of PB and MDF specimens are the weakest part of the joint connection. For unglued edge specimens, butt members of the PB and MDF specimens are also the weakest part of the joint connection both in compression and tension loading. Maximum bending moment strength of the corner joints was a function of loading type, gluing technique, length of specimen and end distance.

Table 6. Stepwise regression coefficients.

VARIABLES STEP	Confidence level	1 X1*	2 X2**	3 X3***	4 X4****	Model of r^2
1	0.95	0.4861	0.2938	0.0671	0.0082	0.8552
2		0.4861	0.2938	0.0671	Reduced	0.8470
3		0.4861	0.2938	Reduced	Reduced	0.7799
4		0.4861	Reduced	Reduced	Reduced	0.4861

* Loading type; ** Gluing technique; *** Length of the specimen; **** End distance

Table 7. Comparison of biscuit with dowel joints in compression and tension tests.

	Biscuit joints	Dowel joints	
	Maximum moment per meter of length (N.m)	Eckelman study Maximum moment per meter of length (N.m)	Guntekin study Maximum moment per meter of length (N.m)
Compression	2.71	2.26	2.03
Tension	3.16	2.83	2.37

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