Shear Force Capacity of Various Doweled Frame Type Furniture Joints

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Abstract
Tests were carried out to determine the ultimate shear force capacity of numerous of doweled frame type furniture joints under controlled laboratory conditions. Sugar maple (*Acer saccharum*), soft maple (*Acer negund*), yellow poplar (*Liriodendron tulipifera*), sweetgum (*Liquidambar styraciflua*) and black walnut (*Juglans nigra*) were utilized in constructing the joint specimens, but all dowels were cut from yellow birch (*Betula papyrifera*) and sugar maple (*Acer saccharum*). Two types of specimens were used in the tests, including “in plane” and “out of plane” positions. Specimens were assembled with polyvinyl acetate adhesive. Specimens were tested under static load by applying shear forces. The results showed that the narrower dowel spacing provide greater shear force capacity for a specified rail width. It was deduced that there was a slight relationship between the shear strength of the wood used in the rail and the thickness of the rail and average ultimate shear force capacity of the joint. It was also demonstrated that the joints had essentially equal shear force capacity regardless of whether they were loaded in the flat wise or edgewise position. Furthermore, the average shear force capacity of dowel joints evaluated in this study could be estimated by developed predictive expressions.
Key Words: Shear force capacity, dowel joints, dowel spacing, in plane position, out of plane position.

Introduction

The design of the joints in a furniture frame is perhaps the most important step in the entire design process. Even though the members may have more than enough strength to carry the forces imposed upon them, if the joints are too weak, the structure may still fail. It is probably safe to say, in fact that more structural failures occur in furniture because of weak joints than from any other single cause. It is important, therefore, that the joints used in the construction of a particular piece of furniture be scientifically designed so that they can safely carry the forces imposed upon them in service (Eckelman, 1968).

The strength and stiffness of joints used in furniture construction will normally determine the furniture’s strength and rigidity. Unfortunately, the seeming propensity of furniture frames toward failure has led to the belief that new, i.e., stronger joints are needed. However, it must be noted that within certain limits, joints are inherently neither weak nor strong. Their strength, in fact, has meaning only in relation to the loads that they must carry in service (Eckelman, 1970).

Dowel joints are perhaps the most popular method of joining members together in wood furniture frame construction. The strength of these joints is somewhat limited relative to the strength of the joined members, so unless they are properly designed, they may be the weakest part of a furniture frame. In a typical furniture frame, dowel joints may be subjected to axial, shear, torsional and / or bending forces (Eckelman, 1968).

A dowel pin is a small wooden cylinder that is used to fasten two furniture components together with or without help of other fasteners and glue. However, if a dowel is used without glue, it is used more to locate parts than a primary joint fastener (Eckelman, 1971). Dowels are the most commonly used connectors for furniture assembly. Dowel joints are well suited for both mass production and small shop production of furniture because they are low in cost and require only simple drilling operation for their construction (Eckelman, 1979).

For maximum strength, dowels cut from woods with high shear strengths such as yellow birch, beech, or sugar maple should be preferred over dowels with low shear strength such as white birch (Eckelman, 1991).

In many types of furniture construction, dowel joints are heavily loaded in shear by horizontal and vertical forces. It is necessary therefore to have a rational means available for designing these joints to meet service needs. The maximum strength of dowel joints might be expected to be limited by the shear strength of the dowels, themselves.

Investigations have been made of the ultimate strength of various types of dowel joints. It was pointed out that the ratio of design strength to ultimate strength based on fatigue requirements also needs to be established. It was suggested that the "fatigue limit" may be as low as 1/6 of the ultimate static strength of the joint (Engleson, 1973). A study of the bending moment capacity of T-type, two-pin dowel joints indicated that the ultimate bending moment capacity (*M*) of the joint could be estimated by means of the expression $M = F \times d$, where F = the ultimate direct withdrawal force of a single dowel and d = the distance between resultant compression and tension forces vectors (Eckelman 1971, Erdil 1994). 60 types of dowel joint specimens were constructed of black walnut and tested in flatwise bending. A set of edgewise bending specimens was included in the study to provide a basis of comparison between edgewise and flatwise bending characteristics. Results of the tests indicated that the strength of the joints could be predicted by means of the formula $F_4 = (D^3/16)\ S_u + F_2\ (W + D)/2$ where F_4 refers to the ultimate bending strength of the joint (*pound-inches*), D is the diameter of the dowel (*inches*), F_2 is the ultimate withdrawal strength of the dowels (*pounds*), S_u is the MOR of the material of which the dowels were constructed (*Psi*), and W is the thickness of the rail (*inches*). According to test results, joints were quite flexible in flatwise bending as compared to edgewise bending (Erdil, 1998). Use of sufficient glue is an important factor for dowel holding strength. Englesson investigated several particleboard based joints in the Swedish Wood Research Institute. He found that double gluing, i.e., applying the glue to both dowels and to the walls of the hole increased strength of a joint 35 percent over gluing the hole alone. He also deduced that the strength of dowel joint could be significantly increased by filling the holes with adhesive so that when the dowel is forced into the hole, the glue penetrates to the surrounding layer of the particleboard (Engleson, 1973).

Studies have been done on the factors that govern the strength and stiffness of a corner block with anchor bold joints and estimates of the strength of this joint that could be used in the rational design of tables have been developed (Hayashi and Eckelman 1986).

In the studies done to determine the effects of different wood species and different dowel measurements on tensile strength, it was found that tensile strength increases when the density of wood type increases. It was also found that 48 *mm* long dowel joints gives better results when compared to 36 *mm* long dowel joints and 10 *mm* diameter dowel joints again gives better results when compared to 8 *mm* diameter dowel joints (Efe 1998a, 1998b).

The bending moment capacity and moment-rotation characteristics of T-type two-pin dowel joints constructed of solid wood and wood composites have been investigated. According to the test results, joints constructed of red oak and plywood had the highest bending moment resistance and the joints of particleboard had the weakest bending resistance. No significant differences on bending resistance between joints constructed of oak and plywood were observed. The ultimate bending moment capacity of the joint could be estimated by means of the formula $M = (d_1/2+w/3+e/3) \times T$, where T=the ultimate direct withdrawal force of a single dowel, w= the width of the rail, e= the distance from the rail centerline to the neutral axis, and d_1= the spacing between two dowel (Zhang et al. 2001)

Construction of the joints in the representative frame is essentially the same as in previous studies (Erdil and Eckelman 2001, Zhang et al. 2002a, 2002b) in order to provide the means for a close comparison of result. Dowel spacing in the front rail to stump joint was 2 inch.

In the studies done on dowel joints prepared with a variety of types of wood it was found that tangential direction and PU adhesive increases the tensile strength (Efe and Demirci 2000, 2001).

In the studies done to determine the effects of end to end dowel joints and side to side dowel joints with different moisture on tensile strength, it was found that oak wood gives better results when compared to beech and pine wood. It was also found that tensile strength decreases when moisture of wood increases (Efe et al. 2002a, 2002b).

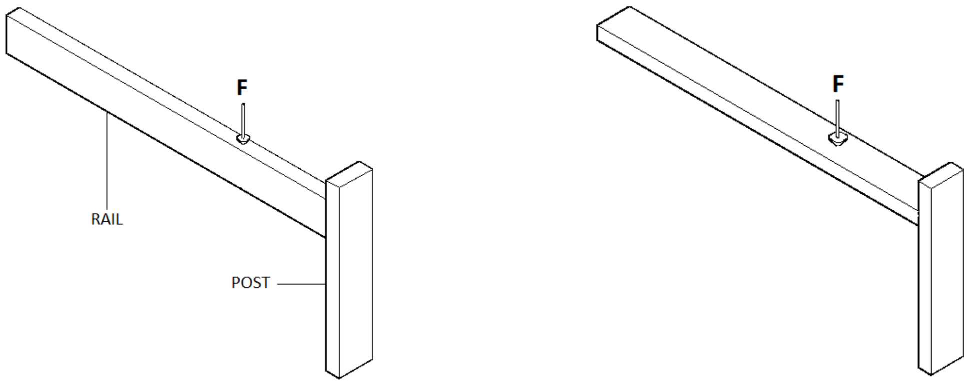
Studies have been done to determine the ultimate shear and bending moment capacity of glued corner blocks under controlled laboratory conditions indicate that they are predictable but are subject to considerable variation. Both the average shear force capacity and the average bending moment capacity of joints formed with various size corner blocks could be predicted by relatively simple exponential expressions (Kasal et al. 2006).

Since a means of predicting the shear force capacity of these joints is vital to the engineering design of furniture frames, a limited study was undertaken to obtain reliable estimates of the shear force capacity of two-pin dowel joints, and to determine if a procedure could be developed for predicting their shear force capacity. The results of these tests are reported in the paper which follows.

General configuration and construction of the specimens

Two general types of specimens were evaluated in the tests. In the first type of specimen, the rail was placed on edge (Figure la) so that "in-plane", normally thought of as vertical loads, could be applied to the specimens. Loads of this type commonly occurs when a person sits down in a chair or sofa, for example. The weight of the person is carried by the seat rails, and seat rails in turn exert vertical shearing forces on the dowels which attach the rails to the posts.

The second type of specimen investigated in the tests is shown in Figure lb. Here, the rail has been placed in the flat position so that "out-of-plane," or what are usually horizontal forces, can be applied to the specimens. Such forces are usually applied to seat rails by seat springs, but other instances of this type of loading also can be cited. Top rails in chairs, for example, normally are loaded in this manner.



a. Edge type (in plane) specimens b. Flat type (out of plane) specimens

Figure 1. The general configuration of two types of specimens evaluated in the tests

All wood species used for constructing the specimens were conditioned to moisture content (MC) of 7 percent. The densities of the wood species used in the tests were 0.70 g/cm^3, 0. 53 g/cm^3, 0. 47 g/cm^3, 0. 58 g/cm^3, 0. 62 g/cm^3, and 0. 66 g/cm^3, for Sugar maple, soft maple, yellow poplar, sweetgum, black walnut, and yellow birch, respectively. The rail portion of each specimen was approximately 500 *mm* long and the post section 250 *mm* long. Each post section was constructed of sweetgum material which had a cross section 22 *mm* thick by 100 *mm* wide. Rail sections were constructed of sugar maple, soft maple, yellow poplar, sweetgum and black walnut which had been conditioned to 7 percent moisture content. All of the dowels were cut from yellow birch and sugar maple dowel rods which had diameter of 10 *mm* and length of 50 *mm*. Measurements were not made of the dowel-hole clearances, but all dowels fit tightly into the holes. The depths of the holes in the end of the rail were carefully controlled, however, so that the dowel pins penetrated exactly 25 *mm* into the end of the rail. It should be noted that a piece of wax paper was inserted between the end of the rail and the side of the post to prevent the rail itself from adhering to the post. A polyvinyl acetate adhesive which had a solids content of about 40 percent was used to assemble the specimens. Double gluing techniques were used in fabricating the specimens, i.e., a liberal amount of adhesive were spread over the dowels and also over the sides of the holes. The species of wood used the cross sections of the rails and the dowel spacing used are given in Table 1.

Table 1. Specimen construction schedule

Set no	Specimen type	Number of specimens	Wood species	Rail cross section dimensions (*mm*)	Dowel spacing (*mm*)	Mean shear force capacity (*N*)	COV* (*%*)
1	Flatwise	5	Sugar maple	22 x 50	25	3550	10,3
2	Flatwise	5	Soft maple	22 x 75	50	4417	27,5
3	Flatwise	5	Soft maple	22 x 100	75	5075	9,7
4	Edgewise	5	Soft maple	22 x 50	25	4915	32,9
5	Edgewise	5	Soft maple	22 x 75	50	3501	8,9
6	Edgewise	5	Soft maple	22 x 100	75	4515	13,9
7	Flatwise	5	Yellow poplar	22 x 50	25	3799	4,9
8	Flatwise	5	Yellow poplar	22 x 75	50	4275	11
9	Flatwise	5	Yellow poplar	22 x 100	75	4902	5,2
10	Edgewise	5	Yellow poplar	22 x 50	25	3723	23,5
11	Edgewise	5	Yellow poplar	22 x 75	50	3536	8,5
12	Edgewise	5	Yellow poplar	22 x 100	75	4252	29,6
13	Flatwise	5	Sweetgum	22 x 50	25	3140	6,8
14	Flatwise	5	Sweetgum	22 x 75	50	5008	6,9
15	Flatwise	5	Sweetgum	22 x 100	75	4862	14,5
16	Edgewise	5	Sweetgum	22 x 50	25	4346	11,1
17	Edgewise	5	Sweetgum	22 x 75	50	4332	12,3
18	Edgewise	5	Sweetgum	22 x 100	75	3914	13,4
19	Flatwise	5	Black walnut	25 x 100	25	6734	13,0
20	Flatwise	5	Black walnut	25 x 100	50	5200	9,3
21	Flatwise	5	Black walnut	25 x 100	75	4906	8,4
22	Edgewise	5	Black walnut	25 x 100	25	5938	6,7
23	Edgewise	5	Black walnut	25 x 100	50	5662	9,1
24	Edgewise	5	Black walnut	25 x 100	75	4595	16,7
25	Flatwise	5	Yellow poplar	25 x 63	25	4332	8,7
26	Flatwise	5	Yellow poplar	25 x 75	25	3874	17,6
27	Flatwise	5	Yellow poplar	25 x 88	25	3834	6,6
28	Flatwise	5	Yellow poplar	25 x 100	25	3816	19,2
29	Flatwise	5	Yellow poplar	25 x 112	25	3790	10,6
30	Edgewise	5	Yellow poplar	25 x 63	25	3683	8,6
31	Edgewise	5	Yellow poplar	25 x 75	25	4310	10,8
32	Edgewise	5	Yellow poplar	25 x 88	25	3576	10,1
33	Edgewise	5	Yellow poplar	25 x 100	25	4248	6,1
34	Edgewise	5	Yellow poplar	25 x 112	25	4426	14,1

*COV: Coefficient of variation

Altogether, 34 sets of specimens consisting of 5 replications for each, or, a total of 170 specimens were prepared and tested. The position of the rail, its cross section, the arrangement of the dowels, and species of wood used are also shown diagrammatically in Figures 2 through 4. These figures show the ends of the rails as they join the posts and help to visualize the relative size and position of the various parts. In Figure 2, dowels were located a constant distance (13 *mm*) from the edges of the rail and all of the rail thickness was 22 *mm*. In Figure 3, rail width was held constant (100 *mm*) and dowel spacing was varied. In Figure 4, dowel spacing was held constant (25 *mm*) and rail width was varied. In Figure 3 and Figure 4, all of the rail thickness was 25 *mm*.

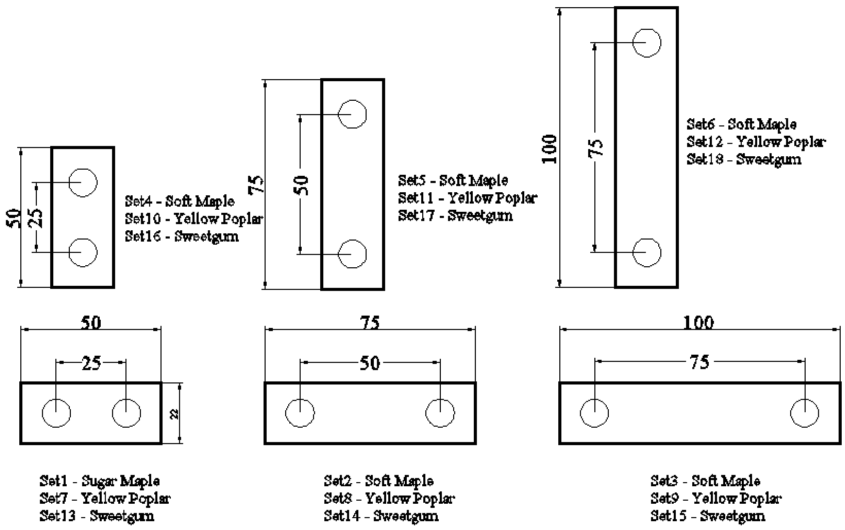


Figure 2. Specimen set numbers, cross section of the rails and placement of the dowels when dowels were located 13 *mm* constant (dimensions *mm*)

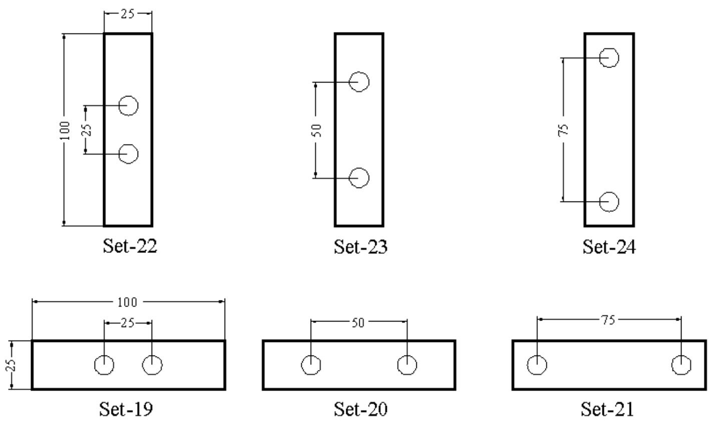


Figure 3. Specimen set numbers, cross section of the rails and placement of the dowels when rail depth was 100 *mm* constant (dimensions *mm*)

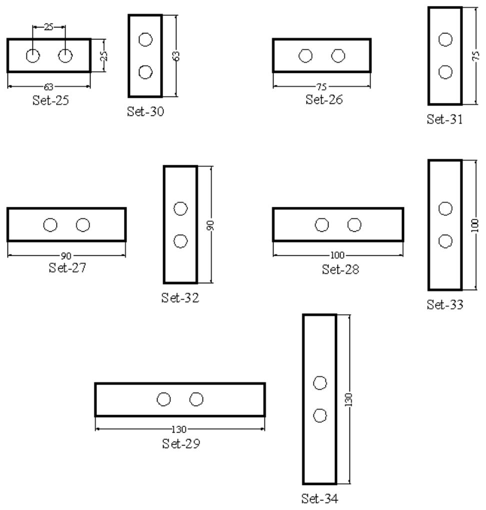


Figure 4. Specimen set numbers and rail cross sections when dowel spacing was 25 *mm* constant and rail depth was varied (dimensions *mm*)

Method of loading and testing

The specimens were arranged for testing as shown in Figure 5. The rail was supported at a point 460 *mm* away from the rail to post joint. Loads were then applied to the rail at a point 150 *mm* away from the joint. By loading the specimens in this way, the ends of the rail were free to rotate relative to the post, as they would in practice because of the deflection of the rail, and also to split.

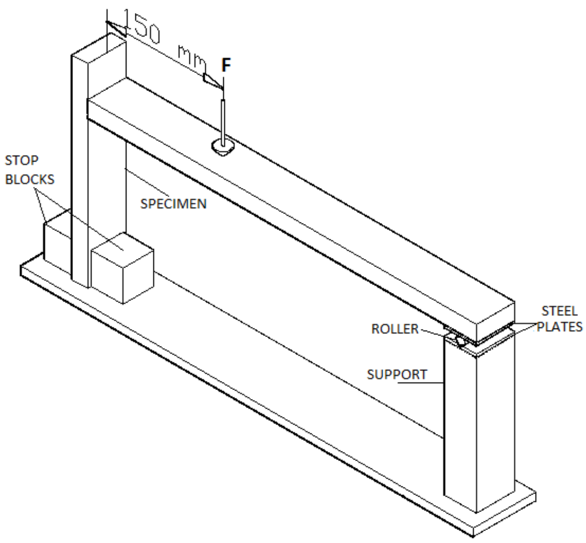


Figure 5. Loading set-up used to evaluate shearing force capacity of the specimens

The exact position chosen for the load and end support were arbitrary, but it was felt that the positions chosen produced a much more representative loading arrangement than if the load point were moved nearer to the joint. This latter arrangement would produce a true shear load, but it would not allow for splitting and the rotation of the end of the rail which are normal for this type of joint. All of the tests were carried out in a universal testing machine at a cross head loading rate of 38 *mm* per minute.

Results and discussion

Average failing loads and other statistical data for each of the specimen types are given in Table 2.

Table 2. Average shear force and correlation with the depth of the rail

Line	Specimen set no	Correlation coefficient	Regression (a_0)	Coefficient (a_1)	Mean (N)	Standard deviation
1	1–18	0,35	711,7	78,7	4212	835,3
2	1–3, 7–9, 13–15	0,74	478,9	164,3	4306	835,3
3	4–6, 10–12, 16–18	-0,04	952,6	-9,1	4114	834,9
4	1–6	0,29	754,7	75,2	4359	1011,0
5	1–3	0,70	461,4	171,5	4341	952,3
6	4–6	-0,16	1121,3	-45,3	4381	1127,6
7	7–12	0,44	654,5	86,5	4052	724,6
8	7–9	0,83	602,5	123,3	4283	549,8
9	10–12	0,27	684,7	59,2	3839	815,8
10	13–18	0,35	735,4	72,8	4243	772,2
11	13–15	0,76	382,4	193,9	4288	995,0
12	16–18	-0,35	1089,2	-48,4	4199	519,1
13	10–12, 16–18	0,03	887,1	5,4	4017	696,6
14	19–24	-0,73	1594,5	-178,3	5360	1289,5
15	19–21	-0,76	1673,7	-205,8	5613	1012,4
16	22–24	-0,70	1515,3	150,8	5400	805,1
17	25–34	-0,03	883,1	-0,97	3990	521,3
18	25–29	-0,32	1063,4	-51,4	3928	520,4
19	30–34	0,39	686,3	64,0	4363	944,8
20	1–34				4363	989,2
21	7–12, 25–34				4017	596,9
22	7–9, 25–29				4057	551,6
23	10–12, 30–34				3981	643,2
24	1, 7, 13				3496	374,1
25	2, 8, 14				4546	761,9
26	3, 9, 15				4951	503,1
27	4, 10, 15				4288	1074,6
28	5, 11, 17				3834	557,3
29	6 12, 18				4208	763,7
30*	1-34	0,34	1003,0	0,314		
31**	1-34	0,32	898,7	0,84		

* Shear strength parallel to grain ** Tensile strength perpendicular to grain

In this table, regression and correlation coefficients for various combinations of specimen sets along with average shear force values and standard deviations are given in lines 1 through 19. Mean values and coefficient of variations are given for the combinations of sets presented in lines 20 through 29. The regression coefficients apply to shear force capacity expressions of the form;

$$F_s = a_0 + a_1D \quad [1]$$

where F_s is the ultimate shear force capacity (*N*) and *D* is the depth of the rail (*mm*). Average shear forces acting on the joint also are listed next to the specimen to whom they apply in Figures 2 through 4. It should be noted here, the values given are the shear forces acting on the joint itself rather than the force applied by the testing machine.

With few exceptions, the specimens failed due to splitting of the rail. At this point, the tensile strength of the rail perpendicular to grain was very important. In a few cases, the wood in the rail and post sections crushed beneath the dowels so that the dowels partially withdrew from the wood and then broke off. In this case, the shear strength of the rail parallel to grain was effective on the strength. No cases of pure shear failure were observed, however.

In order to determine whether or not the ultimate shear force capacity of the joints could be related to parameters according to failure modes such as rail depth, rail thickness, dowel spacing, shear strength of the wood used for the rail parallel to the grain, and tension strength of the rail material perpendicular to the grain, multiple regression expressions were fitted to the data. Both first and second order terms were included in the expression for each of the previously mentioned parameters; i.e.;

$$F = a_0 + a_1t + a_2t^2 + a_3w + a_4w^2 + a_5D + a_6D^2 + a_7S + a_8S^2 + a_9T + a_{10}T^2 \quad [2]$$

where F_s = expected shear force capacity (N), t = thickness of rail (mm), D = depth of rail (mm), d = dowel spacing (mm), S = shear strength parallel to the grain of wood used in rail (N/mm^2), T = tension strength of wood used in rail perpendicular to the grain (N/mm^2), a_0 . . a_{10} = regression constants. When this expression was evaluated, it took the form:

$$F_s = — 1825.4 + 925.2t + 2.34S — 0.00066S^2 \quad [3]$$

The correlation coefficient for this expression was 0.5. The results of this analysis, therefore, indicated that at a 95 per cent confidence level, there was a slight relationship between the shear strength of the wood used in the rail and also the thickness of the rail and average ultimate joint shear force capacity.

Results of the analysis did not indicate any relationship between dowel spacing and joint shear force capacity. In general, all of the relationships between shear force capacity and joint parameters were linear except for shear force capacity where second order effects were indicated. On the basis of calculations which were subsequently carried out while making use of the results of these analyses, it was concluded that none of the relationships examined had any real significance as far as engineering design applications were concerned. However, the results obtained with various combinations of joints were examined further to determine if relationships could be found within certain groups.

Because dowel joints are heavily loaded in shear by horizontal and vertical forces, it is necessary to have a rational means available for designing joints to meet service needs.

The effect of rail depth on shear force capacity when the dowel spacing is maintained at a constant distance from the rail edge was examined first. The results of these tests have been plotted in Figure 6.

Figure 6. Graph showing relationship of average ultimate shear strength versus rail depth for fixed dowel to rail edge distance for various wood species

As can be seen the data points are somewhat scattered and it is difficult to detect any particular trends. When a linear regression line was fitted to this data (specimen sets 1–18, line 1 of Table 2) the correlation coefficient was only 0.35 which indicates that the shear force capacity of the joints were not closely related to rail depth.

The association is much better for the flat specimens, however, than it is for the edge a specimen. When a linear regression line was fitted to the data for the flat specimens (line 2 of Table 2), the correlation coefficient was 0.74 whereas the correlation coefficient for the regression line fitted to the data for the edge specimens (line 3 of Table 2) was only -0.04.

Comparisons among and within the individual species also are of interest. Except for maple, there is reasonable correlation between depth and shear force capacity in each specimen group; that is, within the flat specimen group and within the edge specimen group. Combinations of species within a group produced poor results; however, as shown by the results for specimen sets 4–6, 10–12, 16–18 and for sets 10–12 and 16–18 (lines 3 and 13 of Table 2).

When the width of the rail was held constant and the dowel spacing was varied (Figure 3, sets 19–24) the shear force capacity of the joint varied inversely with the dowel spacing as can be seen in Figure 7.

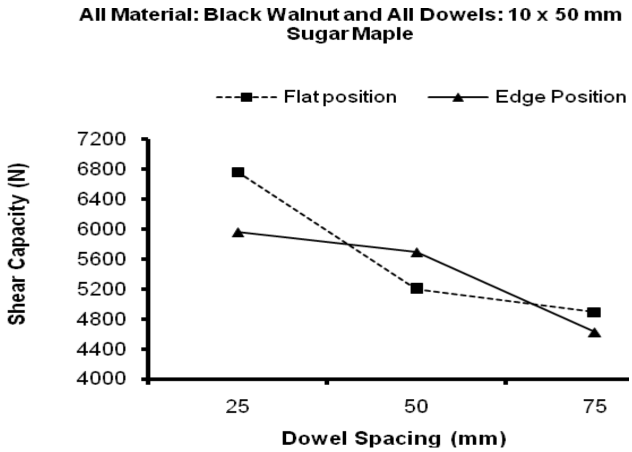


Figure 7. Average ultimate shear strength versus dowel spacing when rail depth is held constant

Here, it can be clearly seen that the narrowest dowel spacing produced the strongest joint both when the rail was laid flat and also when it was placed on edge. The correlation coefficients for the curves fitted to this data (lines 14–16 of Table 2) further indicate that a reasonably close relationship does exist between dowel spacing and shear force capacity. Again, the relationship is slightly better for the flat specimens than it is for those placed on edge.

The relationship between the shear force capacity of the joints and rail width when the dowel spacing is held constant at 25 *mm* is shown in Figure 8, specimen sets 25–34. The scatter of the data reveals few discern-able trends.

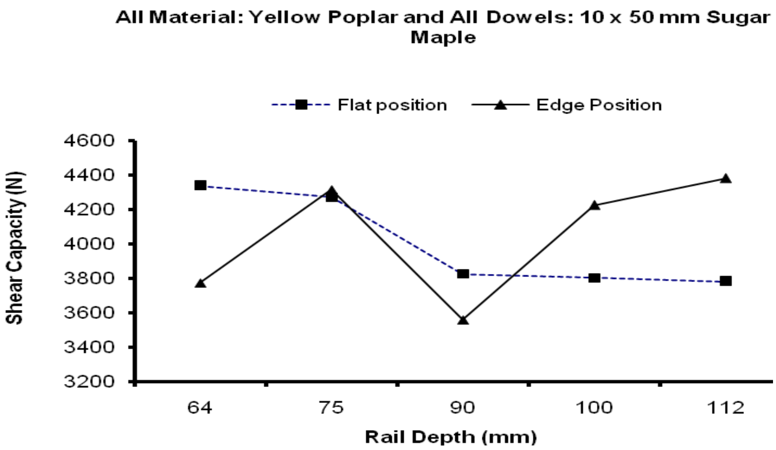


Figure 8. Average ultimate shear strength versus rail depth when dowel spacing is held constant

In the case of the flat specimens, joint shear force capacity actually appears to decrease as rail width increases, and the correlation coefficient for this data (line 18 of Table 2) indicates this inverse relationship.

Analysis also were carried out to determine the relationship of average ultimate shear force capacity of the joints to both the shear strength parallel to the grain and tensile strength perpendicular to the grain of the wood used in the rail. Results of these analyses are shown in lines 30 and 31 of Table 2. Again, a close relationship is not indicated. Average shear force capacity values and coefficient of variations have also been listed in Table 2. These values are particularly interesting since they seem to indicate that on the average there is little appreciable difference in shear force capacity between the specimens tested in the flat wise position and those tested in the edgewise position. Furthermore, the shear force capacity of the 25 *mm* thick yellow poplar specimens (sets 25–34, line 17 of Table 2: 3990 *N*) was nearly identical to that for the 22 *mm* thick specimens (set 7–12, line 7 of Table 2: 4052 *N*).

Results of these tests suggest that factors other than the cross sectional areas of the rails control the ultimate shear force capacity of dowel joints, at least for the size of specimens tested. Certainly, any cross grain near the end of the member would be expected to have a significant effect on the joint shear force capacity since the end of the rail would likely "split out" more easily than if it were straight-grained.

It also seems likely that stress concentrations developed around the holes in the ends of the rails, and that the splitting action, therefore, originated at these points. If this is true, then the rails would begin to split once the ultimate strength of the wood was exceeded at these points regardless of what the average stress acting on the rail might be, and the ultimate shear force capacity of the joint would be largely independent of the cross section of the member for the size specimens tested.

Because of the uncertainties involved, it does not appear reasonable at this time to attempt to devise a shear force capacity formula for dowel joints based on a consideration of the strength of materials alone. Certainly, the development of some such type of design procedure should remain the ultimate objective, however.

One procedure is to simply take the average shear force capacity value of all the joints tested and apply a reduction factor to it to take into account the possible variations in shear force capacity which might be expected.

The average shear force capacity value of all the joints tested (this refers to individual values obtained for each specimen) was 4363 *N* with a standard deviation of 998 *N*. The lowest value observed was 2700 *N*. Let us say that we wish to determine a lower strength value such that even if we continued our tests indefinitely, we could be 95 percent confident that less than one per cent of the specimens would be weaker than this lower bound. This lower bound or tolerance limit can be determined by multiplying the standard deviation by 2.326 (which is the tolerance factor such that the probability is 0.95 that 99 percent of the values will lie above the value given by the mean minus the standard deviation multiplied by the tolerance factor) and subtracting the product from 4363 *N*; i.e.;

$$F_s = 4364 - 2.326 \times 998 = 2865\ N \qquad [4]$$

where F_s is the shear force capacity.

This procedure, therefore, provides us with an estimate of a base shear force value which can be used in subsequent design calculations. It must be recognized here that at least one-percent of the joints constructed might be expected to have less than 2064 *N* shear force capacity.

It should also be noted that this 2064 *N* load value may need to be further reduced for design purposes to provide a suitable factor of safety. There are no simple guidelines which can be used to determine appropriate safety factors for joints used in furniture construction. It is recommended that the base shear force capacity value determined for these joints should be reduced by at least a factor from two to three to account for variables in the manufacturing process.

Conclusions

Tests were carried out to determine the ultimate shear force capacity of numerous of doweled frame type furniture joints under controlled laboratory conditions. Sugar maple, soft maple, yellow poplar, sweetgum and black walnut were utilized in constructing the joint specimens, but all dowels were cut from yellow birch and sugar maple. Two types of specimens were used in the tests, including "in plane" and "out of plane" positions. Specimens were assembled with polyvinyl acetate adhesive. Specimens were tested under static load by applying shear forces.

The results of the exploratory tests carried out indicate the shear force capacity of dowel joints is quite variable and does not appear to be closely correlated with parameters such as member cross section which ordinarily have a considerable bearing on joint shear force capacity. Furthermore, it is apparent from this study that several more factors must be investigated before a design formula can be developed which relates joint shear force capacity to dowel size, member dimensions, and some mechanical property of material used.

One result that did clearly emerge from these tests is that the narrower dowel spacing provided the greater shear force capacity values for a specified rail width. This result is not agreed with the study of bending moment capacities of dowel joints carried by the Eckelman (1971). In the mentioned study, it was concluded that moment capacity of two-pin dowel joints increases when the dowel spacing is increased.

It was deduced that there was a slight relationship between the shear strength of the wood used in the rail and average ultimate shear force capacity of the joint. However, according to Eckelman (1991), the withdrawal strength of a single dowel and bending moment capacity of the two-pin dowel joints is related to shear strengths parallel to the grain of the woods used for dowel and rail. It also appeared that the joints had essentially equal shear force capacity regardless of whether they were loaded in the flat wise or edgewise position. However, according to Erdil (1998), joints were quite flexible in flatwise bending as compared to edgewise bending. In conclusion, it could be said that shear force capacity and bending moment capacity of T-type dowel joints were affected by different factors and they were showed different mechanical behavior properties.

Subject to the limitations imposed by the test, it was statistically determined that we can be 95 percent confident that 99 percent of the joints constructed in a manner similar to the test would have shear force capacity of at least 2064 *N*. This value can then be used as a base for estimating shear force capacity design values for this type of joint since it takes into account variations in material properties. It must be remembered that variations in production line practices must also be taken into account with other factors in order to arrive at allowable shear force capacity design values, and the "base" design value must be modified accordingly to obtain an allowable shear force capacity value to be used in design calculations.

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