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A Comparative Analysis of Furniture Dowel Joint Strength Among Various Dowel Styles

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A Comparative Analysis of Furniture Dowel Joint Strength among Various Dowel Styles

BY

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Abstract

This study examines the effectiveness of various dowels used in furniture joints. Using multiple linear regression, it examines the interaction between dowel penetration depth and surface treatment. Two commercially available surface treatments, fluted cut and spiral cut, were tested against a smooth home-made dowel. Through the bending tests, it was found that depth of penetration had a positive effect on the joint strength. Additionally, home-made dowels were significantly better than both fluted and spiral in softwood tests, and the home-made and the spiral were significantly better than the fluted in the hardwood tests.

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Introduction

This study used destructive testing to determine the cost effectiveness of various commercially available dowels in dowel joint furniture construction. Dowels are used in furniture making to increase the strength of a joint. There are currently several different styles of dowels on the market. The goal of the project is to determine if there is a structural benefit gained from using special cut dowels such as fluted cut and spiral cut. Comparisons were made among spiral cut dowels, fluted dowels, as well as home-made smooth dowels. Further investigation examines the effect of depth on the strength of the joint for these three dowel types. Recommendations are made based on the considerations of joint strength and the relative cost of the dowels. These results will allow consumers to have accurate information on the dowels they are purchasing.

Rationale

This study will provide consumers with accurate information on new specialty cut dowels. The information will not only help consumers save money in the end, it will also provide useful data as to which style of dowel forms a stronger furniture joint. The insight will enable furniture makers to create stronger furniture.

Purpose

This study will examine the relative strength of each fluted and spiral cut dowels to determine if they have a structural advantage over smooth home-made dowels.

Research Questions

Seeing the dowels that are sold throughout trade magazine and to craftsmen, the research is driven by the following questions:

1. Do dowels with flutes or spirals actually improve the strength of the dowel joint?
2. Does the surface of the dowel joint create an effect on the strength of the dowel joint compared to what has been previously observed?
3. What other inhibitors or benefits exist in using spiral or fluted dowels?

Hypothesis

To test the research questions, the following hypotheses are made for each hardwood and softwood. The hypotheses basis on the style of the dowel are below. These are to test that the required forces for the extraction of the dowels are statistically equal.

$$H_O: F_S = F_F = F_R$$

$$H_A: F_S \neq F_F \neq F_R$$

The hypotheses for based around the length of the dowel are below. These are to test that the required forces for extraction of the dowels are statistically equal.

$$H_O: F_{1\frac{1}{2}} = F_2 = F_{2\frac{1}{2}}$$

$$H_A: F_{1\frac{1}{2}} \neq F_2 \neq F_{2\frac{1}{2}}$$

Literature Review

Dowels or rods of wood have been used in joinery for hundreds of years. There is a range of styles of dowels. Over the years, there has been great advancement in wood joinery. However, dowel pins remain widely used by many craftsmen. Over the years, different studies have been carried out testing dowels to their limits. In a study by Carl Eckelman (1969), dowels were put to the test to measure the effects of using different lengths and diameters. His results concluded that increasing the length of a dowel does increase the strength of the joint, but this effect does not continue indefinitely. At a certain length, there is no added benefit to the additional dowel material. This information helped created a foundation for our research, and narrowed the window for lengths of the dowels used in our test. Later, Eckelman followed his research with another dowel study. This time he measured the effects of dowel spacing and the relationship they have with the ultimate strength of the joint (Eckelman, 1971). Data from the test provided insight into what the optimum spacing for dowels in furniture joints should be. While this study does not directly compare the effect of dowel length and diameter or dowel spacing, it does take this information into consideration. This study is being conducted to compare the strengths of different styles of specialty cut dowels. In order to focus the test on the style of the dowel other factors must be eliminated. Using the information provided by Eckelman, factors such as dowel length and diameter as well as spacing can be eliminated more easily. In the studies done by Eckelman smooth dowels were used for testing. Today there are various new styles of dowels on the market. In response to these new styles of dowels further research was conducted to conclude how theses styles of dowels affect the strength of joints.

The type of wood species is a major factor in the strength of a joint. Because of this, it became obvious that different species of wood had to be tested to see if there is any variance between these species in their ability to form a strong furniture joint. Information presented by the USDA Wood Handbook (2010) details the difference between the various species of wood. There are two broad classes of wood species; hardwoods and softwoods. According to the USDA, these category titles can be a bit misleading. In fact, some hardwoods can be softer than several softwoods. The same goes for softwoods. Several species are harder than some hardwoods. The generalization of the categories is based on the cellular structure of the wood itself and not the density of the wood. This cellular structure can influence the strength of a joint. Depending on the cellular structure of a particular species of wood it may have greater or lesser ability for glue adhesion. The cell structure of a hardwood is very porous and contains vessel elements. This means that the cells in the wood are open ended. When a tree is alive these open-ended cells are used to transport sap and water. A study published by the United States Department of Agriculture's (USDA) Forest Products Laboratory in their Wood Handbook states, "High-density woods are difficult to bond" (USDA, 2010). The reason for the bonding difficulty is the structure of the cell walls in the wood. In high-density woods, the cell walls are thicker. The cells are also smaller in diameter. The small cells mean the glue has little to adhere to. The USDA has a crude category guide for the different species and their performances when being glued. A hardwood such as white ash is categorized as bonding satisfactory, which on a rating scale of 1 to 4 would be a 2. A softwood such as pine bonds easily and was given a score of 4 out of 4.

This data gives a great insight to what some potential outcomes may occur in this study. In this study both hardwoods and softwoods are used, as it is apparent that the material the joint is constructed out of has an influence over the overall strength of the joint. Results in this study will be concluded separately for both hardwoods and softwoods.

Methodology

To test the hypothesis, a method was created to examine the strength of the dowels in a furniture joint. Several variables can affect the strength of a furniture joint. It was found that the factors that could affect results of the strength of the joint are the size of the boards, species of wood used in dowel and the species of wood used as the rails that form the joint. Other factors are the amount of glue used in the joint and the depth and spacing of the holes.

Several methods were used to factor each variable so that only the style of the dowel was being put to the test. One variable that needed to be eliminated was the amount of glue. Glue is a key ingredient in the strength of a dowel. Without glue dowels could simply slide out. To factor the glue out of the equation each dowel was completely submersed into a tub of aliphatic resin emulsion (adhesive glue). *Titebond II,* a poly-vinyl acetate glue, was chosen based on its ratings and that is widely used in the furniture making industry. The submersion method meant that every dowel had a sufficient amount of glue. It also meant that each dowel had the same amount of glue on it. Since every dowel had the same amount of glue on it when it was put into the hole it was eliminated as a factor.

The following process was used to construct the furniture joints for the test; two boards which were ten and half inches long by three quarters of an inch thick and two and a half inches wide. Each board was drilled using a dowel hole jig on a drill press to ensure that all the holes were evenly spaced and drilled to the same depth. The use of this method prevented some holes from being drilled deeper, which would allow for different levels of glue adhesion. The two boards were assembled with one board perpendicular to the other, creating a right-angle T- type joint. This type of joint creates an end-to-side grain joint. To clarify between the two wooden joint members the horizontal member can be referred to as the "rail" and the vertical member as the "post". (Refer to figure 1.) This method of testing was chosen based on similar tests done by Eckelman in his research on bending strengths dowel joints. To keep everything consistent 3/8-inch birch dowels were used in all test. Once assembled every joint was allowed to cure for at least a twenty-four-hour period before any testing was conducted. (Refer to figure 2.) To compare the strength of the dowels in several types of materials both hardwood and soft wood was used to construct the T-joints. White ash (*Fraxinus americana*) was used for the hardwood and southern yellow pine (*Pinus spp*) was used for the softwood. Both species were stored in the same environment to create a moisture equilibrium across all samples. Ninety samples in total were built; forty-five were used for the ash and the other forty-five for the pine. The forty-five samples for each type of wood were broken down into three categories. The categories are based on the length of the dowels. Categories are 1 ½ inches, 2 inches, and 2 1/2 inches. Each of these categories contained the three different style of dowels (smooth, fluted, spiral). Five samples were tested for each style of dowel in each category of length in each type of wood.

To test each sample for its breaking strength, a bending force was applied on to the rail. The "T" shaped joint was placed in a SATEC Universal Testing Machine with the post secured with two locking pliers to a support beam on the machine. A downward force was applied two inches from the joint on the rail. Force was applied until the arm hit the bottom of the machine. (Refer to figure 3.) The peak amount of force was recorded on each sample. The peak force on each sample was recorded and compared against each style of dowel.

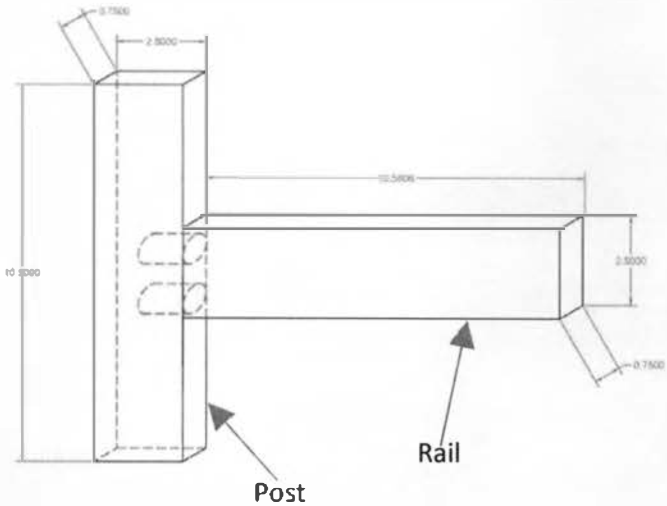

Figure 1.

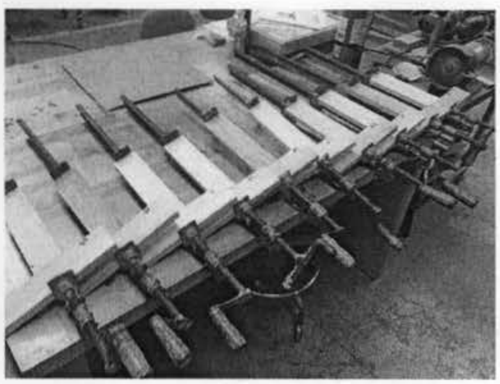

Figure 2.

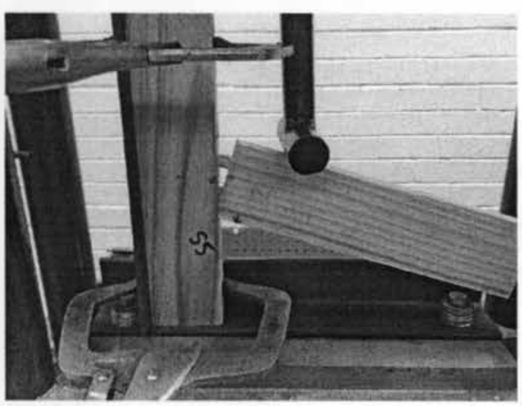

Figure 3.

Results

White Ash

The results from testing showed that the depth of hole and the length of the dowel are statistically significant when creating a joint out of white ash. The average breaking point for a 1 ½ inch dowel is 444 lbs., whereas the average breaking point for a 2 ½ inch dowel is 526 lbs. Statistically based on the P-value the depth of the hole and the length of the dowel are statistically significant. A P-value of 0.024 shows that the length of the dowel is a statistically significant factor in the probability of forming a higher performing joint. The testing was centered around the ultimate breaking point of the joint. However, the way in which the joint broke was also recorded. The types of breaks were categorized in two ways either as a break of the dowel or as an extraction of the dowel. The frequency of breaks as opposed to extractions significantly increased when the length of the dowel was increased. One out of fifteen samples of the 1 ½ inch dowel had joint failure because of a broken dowel. When the length was increased to 2 ½ inch the frequency of breaks increased to nine out fifteen. When using ash, the fluted style of dowel was statistically less likely to perform with a higher load. The fluted dowel had an average breaking point of 449 lbs. Dowel styles such as the spiral had an average breaking strength of 539 lbs. and the smooth dowel style had an average breaking point of 547 lbs. The averages were taken from all three lengths of dowels used in the study. The style of dowel was found to be statistically significant based on the P-value. A P-value of 0.048 towards the style of dowel was found. This indicates that the style of dowel does in fact matter when choosing a style of dowel

When the length and style of dowels were assessed together there was a less convincing P-value. A value of 0.226369 was found suggesting that there is no statistical significant to both the style and length.

Southern Yellow Pine

Results show that the depth of the hole and the length of the dowel are statistically significant when using dowels in soft woods such as southern yellow pine. Longer dowels such as the 2 ½ inch dowel had an average breakings strength of 445 lbs. Shorter 1 ½ inch dowels had an average breaking point of 324 lbs. This resulted in a P-value of 5016E-08. This value proves there is a statistical significance in the length of the dowel. That means it is very likely the longer the dowel the greater breaking point the joint will be able to handle. When using southern yellow pine a smooth dowel pin is statistically significantly better than the fluted or spiral dowel pins. The average breaking point of a smooth dowel pin is 413 lbs. The fluted and spiral dowels had an average breaking point of 348 lbs. and 374 lbs. respectively. The numbers also create a statistically significant P-value of 0.001. This P-value means that it is statistically very unlikely that the style of the dowel has no effect on the strength of the joint. When the both the style and length were compared together they were found to be statistically significant as well. This suggest that the both the length of the dowel and the style of the dowel in the right combination does have an effect over the ultimate strength of the joint.

Anova: Two-Factor with Replication: *White Ash*

1.5 Inch	Smooth	Flute	Spiral	Total
Count	5	5	5	15
Sum	2287	2042	2336	6665
Average	457.4	408.4	467.2	444.3333
Variance	2691.3	2037.8	4946.7	3473.381

2 Inch	Smooth	Flute	Spiral	Total
Count	5	5	5	15
Sum	2769	2780	2906	8455
Average	553.8	556	581.2	563.6667
Variance	932.7	955	9074.2	3297.524

2.5 Inch	Smooth	Flute	Spiral	Total
Count	5	5	5	15
Sum	3025	1910	2962	7897
Average	605	382	592.4	526.4667
Variance	5607.5	90439	4681.8	39988.55

Total	Smooth	Flute	Spiral	Total
Count	15	15	15	
Sum	8081	6732	8204	
Average	538.7333333	448.8	546.93333	
Variance	6649.495238	32975.6	8771.781	

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F critical*
Sample	111850.8444	2	55925.422	4.147198	0.023942	3.259446
Columns	88926.97778	2	44463.489	3.297228	0.048427	3.259446
Interaction	80241.42222	4	20060.356	1.487593	0.226369	2.633532
Within	485464	36	13485.111			
Total	766483.2444	44				

Anova: Two-Factor with Replication: *Southern Yellow Pine*

1.5 Inch	Smooth	Flute	Spiral	Total
Count	5	5	5	15
Sum	1530	1754	1580	4864
Average	306	350.8	316	324.2667
Variance	954	1117.2	544	1142.21

2 Inch	Smooth	Flute	Spiral	Total
Count	5	5	5	15
Sum	2079	1560	1872	5511
Average	415.8	312	374.4	367.4
Variance	3023.2	1418	1166.3	3552.4

2.5 Inch	Smooth	Flute	Spiral	Total
Count	5	5	5	15
Sum	2598	1917	2164	6679
Average	519.6	383.4	432.8	445.2667
Variance	6680.3	2207.8	1170.7	6269.781

Total	Smooth	Flute	Spiral	Total
Count	15	15	15	
Sum	6207	5231	5616	
Average	413.8	348.7333	374.4	
Variance	11194.46	2267.781	3259.257	

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F critical*
Sample	112823.5	2	56411.76	27.77156	5.06E-08	3.259446
Columns	32224.04	2	16112.02	7.931964	0.001399	3.259446
Interaction	48151.42	4	12037.86	5.926248	0.000904	2.633532
Within	73126	36	2031.278			
Total	266325	44				

Conclusion

Hardwood

Is there a structural gain from using "special cut" dowels such as a spiral and fluted cut over the traditional smooth cut dowel? If you find yourself asking this question then next ask yourself what type of wood am I constructing my joint out of. In the event, you are building a joint out a hardwood then using a dowel of at least two inches has a statistically greater chance of holding more weight. This data falls right in line with the data from the testing done by Eckelman in 1969 where he concluded that the point where the was no longer any structural gain was 3- ½ inches. While we did not use dowels to that length, we can confirm a dowel with a length ranging from 1-1/2 inches to 2-1/2 inches has, on average, a higher breaking point. When using a hardwood for a joint, the style of dowel is statistically significant to the overall strength of the joint. Using a smooth or spiral cut dowel created a statistically greater chance of having a stronger joint than if the joint had fluted dowels in it. The depth of the joint showed a statistical significance. However, there is currently no conclusion as to which dowel is best suited for use in a hardwood such as white ash. The reason being, the P-value indicates that there is no statistical significance when comparing both the length and style. Since this value is not statistically conclusive no recommendation can be made based on this data.

Softwood

Softwoods like hardwoods have a greater average breaking point if longer dowels are used. Reconfirming what we know based on Eckelman's work. The joint becomes statistically more likely to hold a greater weight if the dowel is at least 2 1/2 inches long. When using a softwood such as southern yellow pine the style of dowel should be considered. In softwoods, a smooth dowel offers a statistically great advantage. A smooth dowel has a greater average breaking point than both the fluted and spiral cut dowels. In this research, the softwood data is much more conclusive than the hardwood data. For example, the P-value for the hardwood test in the category of style is 0.048 whereas the P-value for the same category in a softwood is 0.001. While the P-value for the hardwood is still a strong value, the value for the softwood is entirely conclusive. This affect can be linked to the structural design of the cells in hardwoods as opposed to the design of the cells in softwoods. As mentioned earlier, softwood is ranked as easily bondable. The cellular structure of the softwoods allows for greater glue adhesion than hardwood. It's no surprise to see the results from testing show that the softwoods to be more consistent than the softwood. Since the softwood is more bondable there is a greater consistency in each sample.

Future Research

To take this research a step further, several types of hardwoods and softwoods could be tested to see if certain species have a significant influence on the strength of the joint. In future research, another step should be taken to see how exactly the joints fail internally inside the hole. This view could reveal why certain samples broke instead of extracted. A time study of assembly time of the joints and for the smooth dowel a cut time could also be assessed; this study would beneficial to this research. In this research, some dowels styles took longer to assemble than others this information was not recorded on this study. Knowing how much time was spent for on average for each style of dowel would shine a brighter light onto to which dowel is more cost effective.

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Appendix: Data Tables

White Ash 1.5						
	Spiral		Smooth		Fluted	
	Breaking Point	Type of Break	Breaking Point	Type of Break	Breaking Point	Type of Break
1	554	Extraction	523	Extraction	385	Extraction
2	437	Extraction	383	Extraction	478	Extraction
3	424	Extraction	454	Extraction	425	Extraction
4	392	Extraction	443	Extraction	361	Extraction
5	529	Extraction	484	Break	393	Extraction
Average	467.2		457.4		408.4	

Southern Yellow Pine 1.5						
	Spiral		Smooth		Fluted	
	Breaking Point	Type of Break	Breaking Point	Type of Break	Breaking Point	Type of Break
1	326	Extraction	340	Extraction	344	Extraction
2	306	Break	321	Extraction	371	Extraction
3	330	Extraction	283	Extraction	371	Extraction
4	280	Extraction	265	Extraction	295	Extraction
5	338	Extraction	321	Extraction	373	Extraction
Average	316		306		350.8	

White Ash 2.0						
	Spiral		Smooth		Fluted	
	Breaking Point	Type of Break	Breaking Point	Type of Break	Breaking Point	Type of Break
1	558	Break	578	Break	503	Extraction
2	521	Extraction	522	Extraction	560	Break
3	515	Extraction	585	Extraction	579	Extraction
4	747	Extraction	563	Extraction	577	Extraction
5	565	Break	521	Extraction	561	Break
Average	581.2		553.8		556	

Southern Yellow Pine 2.0

	Spiral		Smooth		Fluted	
	Breaking Point	Type of Break	Breaking Point	Type of Break	Breaking Point	Type of Break
1	364	Extraction	457	Extraction	266	Break
2	348	Break	369	Extraction	291	Extraction
3	339	Extraction	373	Extraction	321	Extraction
4	411	Extraction	491	Extraction	367	Break
5	410	Break	389	Extraction	315	Extraction
Average	374.4		415.8		312	

White Ash 2.5

	Spiral		Smooth		Fluted	
	Breaking Point	Type of Break	Breaking Point	Type of Break	Breaking Point	Type of Break
1	673	Break	520	Extraction	659	Extraction
2	637	Break	564	Break	79	Break
3	499	Extraction	577	Extraction	593	Break
4	554	Break	661	Break	546	Extraction
5	599	Break	703	Break	33	Extraction
Average	592.4		605		382	

Southern Yellow Pine 2.5

	Spiral		Smooth		Fluted	
	Breaking Point	Type of Break	Breaking Point	Type of Break	Breaking Point	Type of Break
1	451	Extraction	450	Extraction	414	Extraction
2	474	Break	474	Extraction	428	Extraction
3	390	Break	629	Extraction	394	Extraction
4	443	Break	585	Extraction	308	Extraction
5	406	Break	460	Extraction	373	Extraction
Average	432.8		519.6		383.4	