Gluing and Furniture Design

Franklin International

Contents

The satisfaction from a piece of furniture comes not only from its initial appeal to the prospect but also from its continued attractiveness with use. Both its durability and its pristine appearance are important. The integrity of the joints is important to both of these aspects.

Optimum furniture design should be a prime concern of the furniture manufacturer as it allows more latitude and assures more durability under use conditions. Many adhesive problems are due not only to inadequate workmanship but also to inadequate design. Over-design in many cases may compensate for poor workmanship. With some designs it is impossible to obtain adequate strength for good durability.

Destructive forces may be (1) applied from the exterior of a joint or (2) be induced by internal forces. External forces may be those applied by sitting on a chair or racking caused by pushing a case across a rough floor. Internal forces may be from shrinking of wood parts or the steady pull of poorly mated parts forced together by clamping pressure. Adequate structural design will alleviate the first type while correction for the second type may be concerned with good manufacturing practice, such as selection of wood species, uniformity of moisture content, and joint accuracy.

There is considerable latitude possible in joint design between a plain butt joint and a joint designed for maximum strength and durability. Some of these may even cause little or no change in external appearance. In other instances, such as with upholstered furniture, considerable breadth in design of the connection is possible if the joint does not show in the finished item.

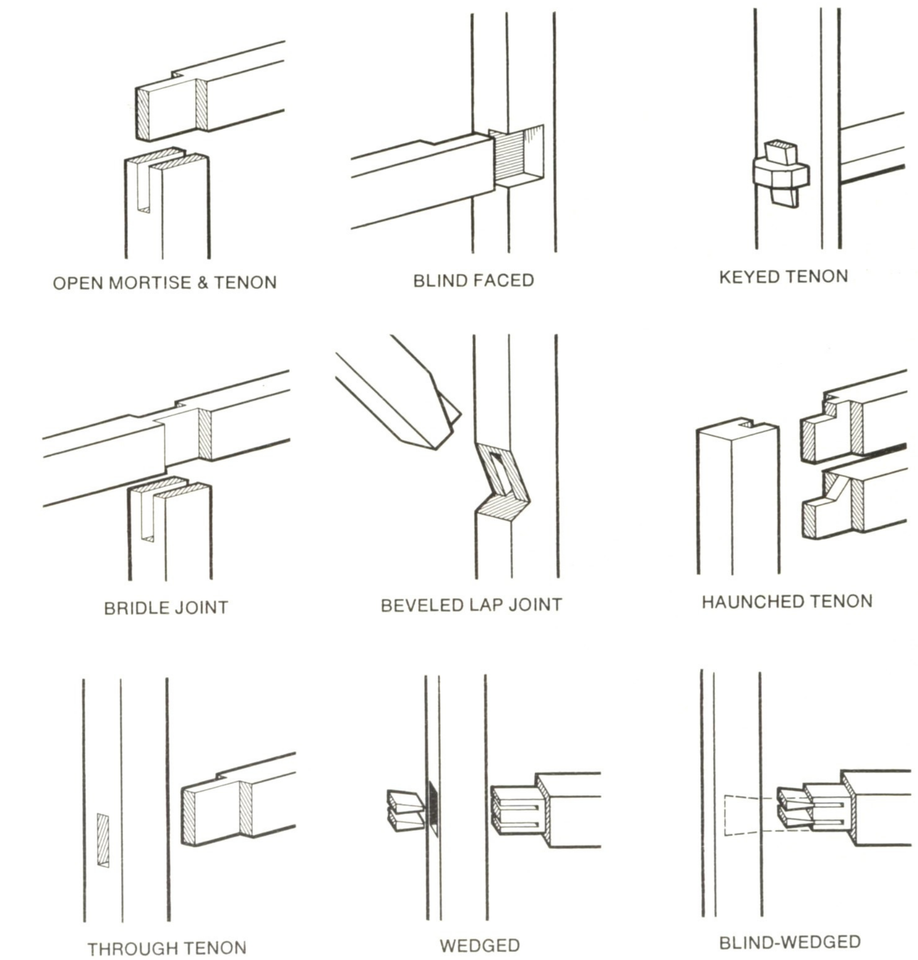
The quality of a connection between two wood pieces is dependent on the type of joint, joint design, manufacturing proficiency and adhesive. This report is concerned primarily with types of joints and their design.

Types of Joints

With most wood species, joints between side-grain and flat-grain surfaces can be made as strong as the wood itself. However, in furniture manufacturing, it is necessary to use less desirable grain relationships. Plain butt end grain to end grain or plain butt end grain to side grain joints have little strength. Modifications of these joints are being used which either (1) incorporate side to side joints or (2) minimize the angle of slope of the wood grain to the glue line. Dovetail, dowel, mortise-and-tenon, spline and blocked joints utilize edge glued surfaces to join parts coming together at right angles. Scarf, finger and miter joints reduce the slope of the grain to the glue line for end-to-end joining of parts.

Mortise-and-Tenon joints

There are many ways of making various types of joints. Selection of a particular variation may be dependent on furniture design, joint location, or stress applied to the joint. The use of a wedged or keyed tenon would improve an ordinary tenon, where the fit is not good.



Mortise-and-tenon joints

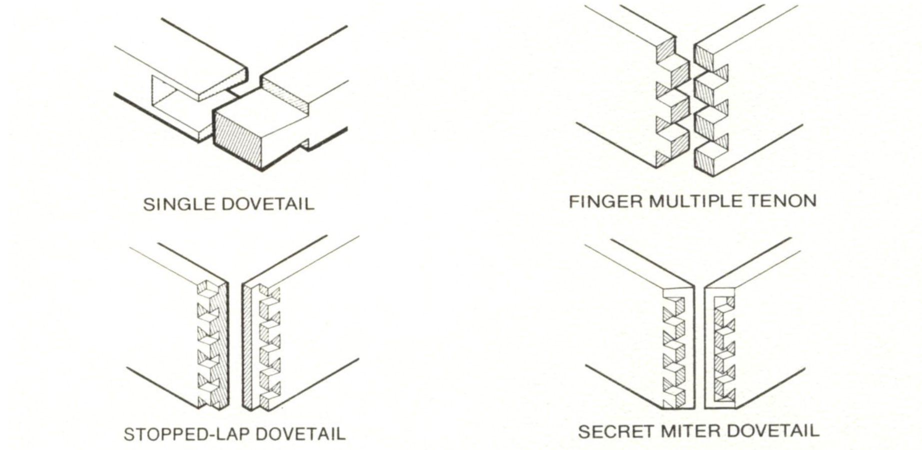
Edge glued panel

Wedged tenon

This cart shows an example of a face glued panel in the butcher block top.

Dovetail joints.

Dovetail joint may be designed as multiple tenon or a locked dovetail joint. A single dovetail is useful in making a table base in which multiple s are attached to a central post or in making a French dovetail. With a dovetail, the shear strength of the wood is added to the glue strength to reinforce this highly stressed joint. The photo in the lower right shows a pinned dovetail joint.

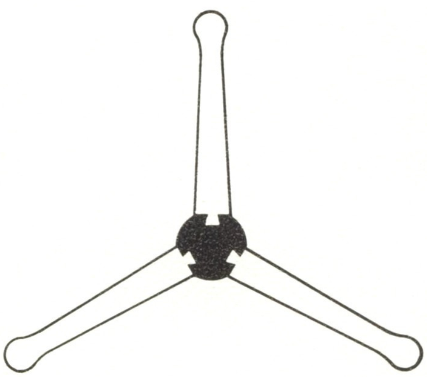


Dovetail joints

Half-lapped dovetail

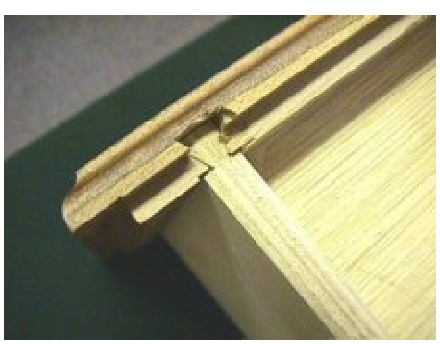


Examples of table leg



Tripod table base. (From “Furniture Treasures”. Lester Margon, The Home Craftsman Publishing Corp., N.Y., N.Y.

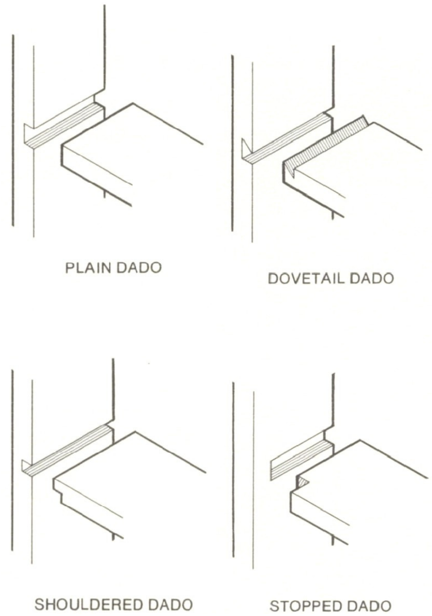
Pinned dovetail



French dovetail

Dado joints

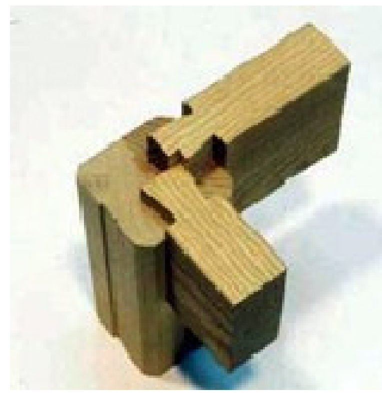
Another joint commonly used is a dado joint. This is a poor joint for gluing as it has the same deficiency as an end-to-side grain joint: low glue joint strength. The dovetail dado does have more strength than a plain dado as the shear strength of the wood prevents the rupture of the joint.



Dado joints

Plain dado

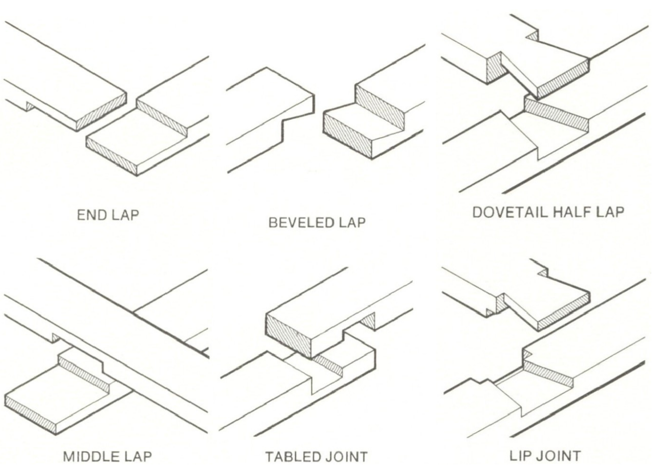
Stopped dado



Dovetail dado

Lap joints

A well-made lap joint is a strong joint in that the glued surface is a face-to-face surface.

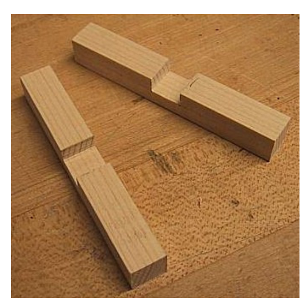


Lap joints

Mitered lap joint

Dovetail half lap

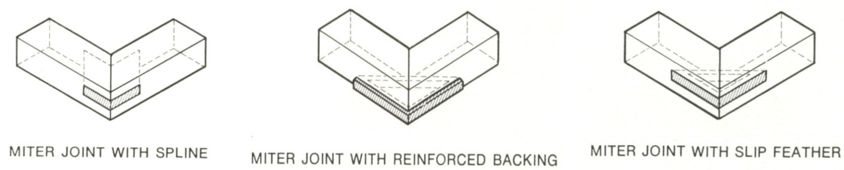
Beleved lap



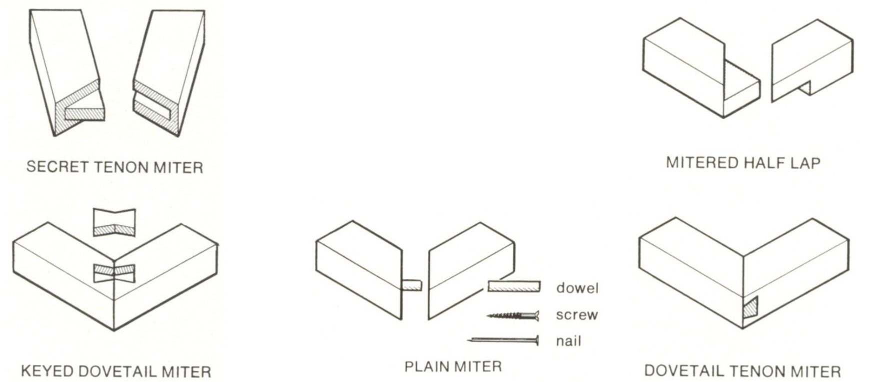
Cross lap members

Miter joint

Miter joints are very commonly used. The 45° glued miter joint is stronger the end-to-end or end-to-side joints, but not nearly as strong as face-to-face glued joints. For a high quality mitered joint, various modifications are possible which contribute to the strength of this construction.



Miter joint construction modifications

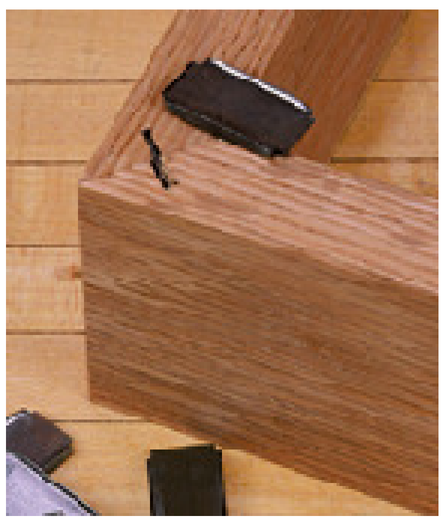


Miter joints

Double slip mortise and tenon miter joint

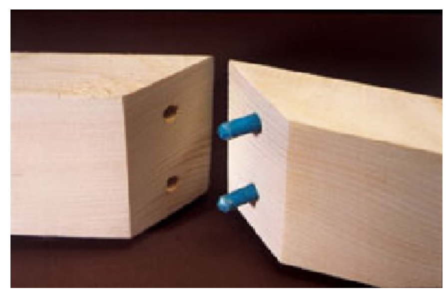
Miter joint with biscuits

Locking miter joint



Miter with joint nails

Mitter joint with splined tenons

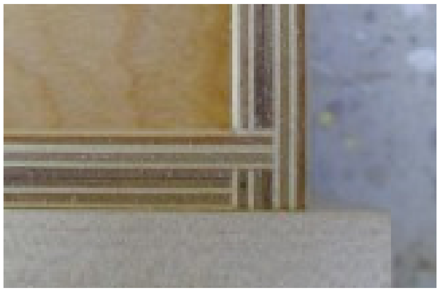


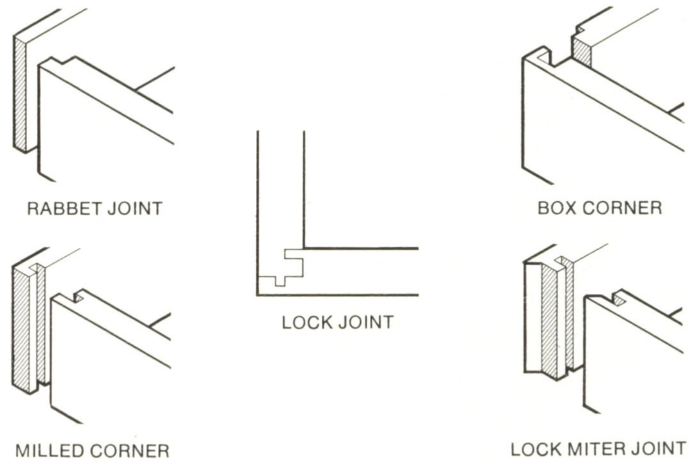
Doweled miter joint

Miter joint with a loose tenon

Corner joints

Various types of corner joints are used. The effectiveness of any one glued joint is related to the amount of glued surface available as well as the accuracy of the maching obtained.

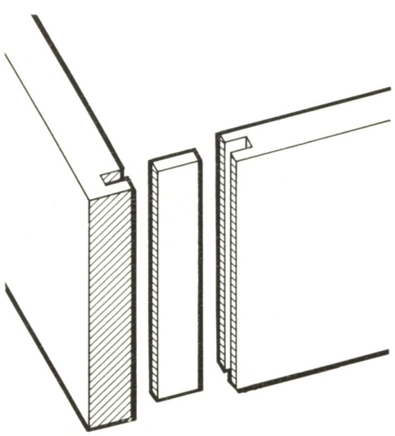

Lock corner joint

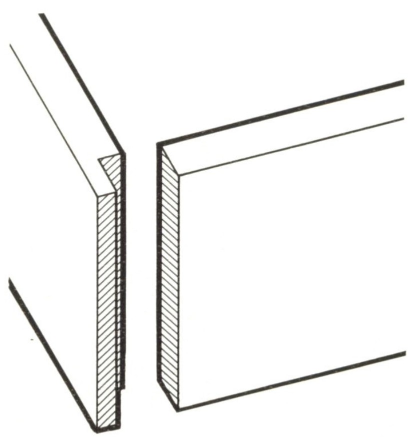


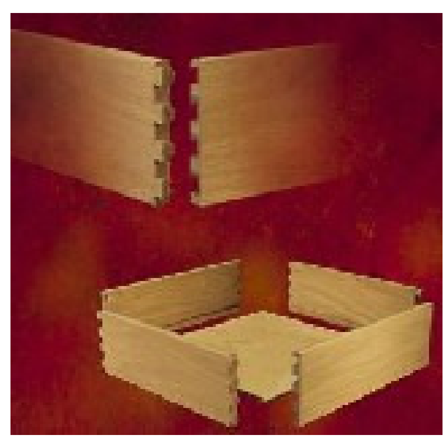
Corner joints


Rabbeted corner joint


Lock corner miter


Splined corner joint


Rabbeted corner joint


Dovetail corner joint

Figures 1 and 2 show the construction of an Egpytian chair three to four thousand years old which employs a complex array of mortise-and-tenon joints and which is intact today.

Blocked Joint

Figure 3 shows a blocked joint. Although this joint features a face-to-face gluing surface, varying moisture content will cause a differential wood movement, since the grain direction of the block and the substrate are at right angles to each other. This will highly stress the joint. Because of this, a number of short blocks is preferable to one long one.

Tongue-and-Groove Joint

A tongue-and-groove joint allows accurate alignment of the pieces being blued. When used, as in Figure 4, it allows some face-to-face gluing surface. This particlar joint is subject to the same stresses as the blocked joint.

The configuration of some joints is such that a minimum stress is applied to the glue line. The glue is required to maintain the assembly but the major disruptive forces are applied almost entirely to the wood, so in these joints, inadequate glue application is not as serious.

Pinning of joints also makes a lock joint in which the major stresses are applied to the wood (Figures 5, Figure 5a and 6).

Figure 1: Egyptian chair

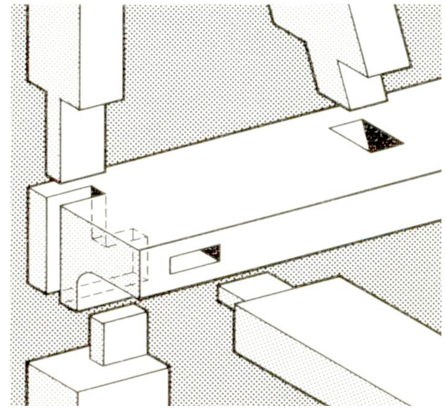


Figure 2: Details of the chair in Figure 1 from “Furniture in the Ancient World”, H.Baker, The MacMillan Co., New York, NY, 1966

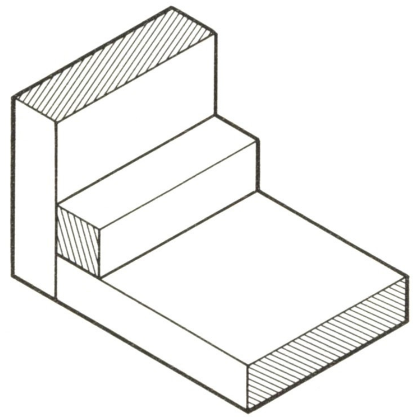


Figure 3: Blocked joint

Figure 5: Chair with wood-pinned side rail and leg

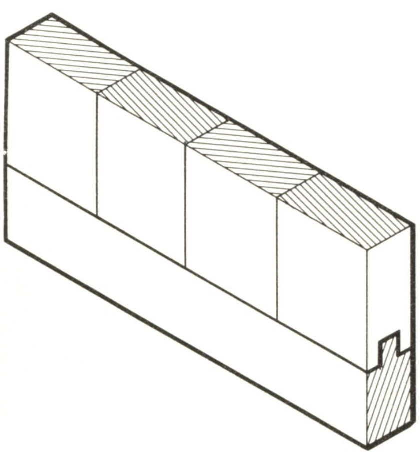


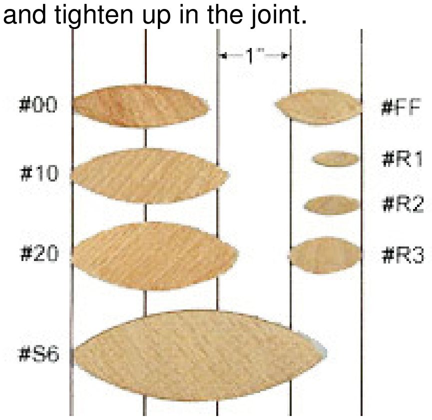
Figure 4: Tongue-and-groove joint

Figure 5a: Pieces for a doweled mortise and tenon

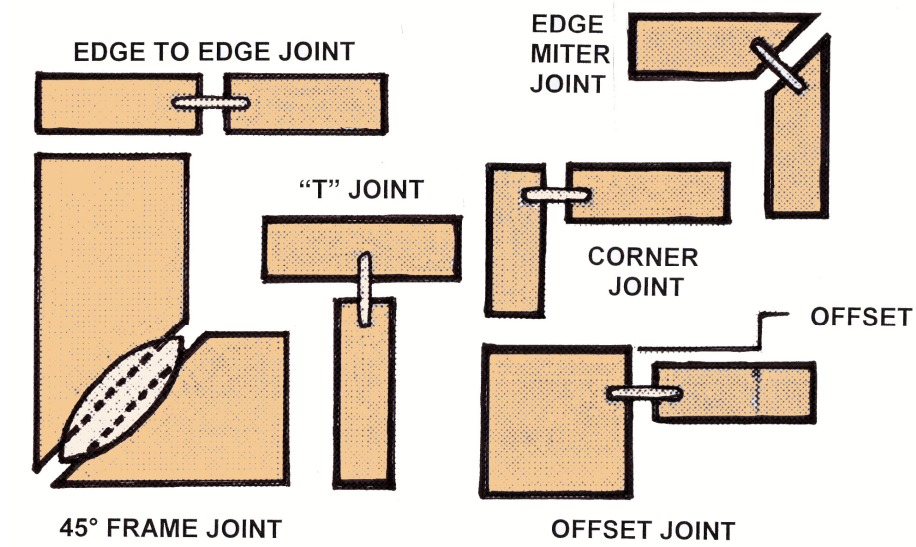
Figure 6: Egyptian chair with joints pinned decoratively with ivory

Biscuit or Plate Joints

A biscuit joint is reinforced with an oval wooden biscuit, half of which is inserted into a crescent shaped hole in the opposite edges of the two pieces of wood. The biscuits are made from compressed beech wood stamped into an oval shape. Water based glues will soak into the biscuit, causing it to swell and tighten up in the joint.



Biscuits and their varying sizes

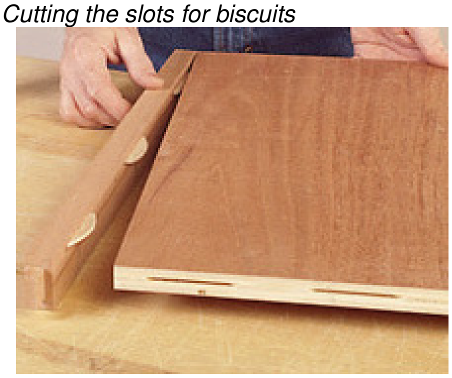


Various joint configurations that can utilize biscuits for additional strength

A special glue applicator for biscuit slots

Cutting the slots for biscuits

Using biscuits to reinforce a t-joint



Dry assembly ensures proper alignment

Biscuits used to reinforce part of a tabletop

A biscuit used to reinforce a corner joint

An unusual application for biscuits

Pocket Hole Joinery

Pocket hole joinery involves drilling an angled clearance hole and a counterbore into a piece of wood and joining it to another piece of wood with a screw. Most people also use a wood glue in conjunction with this method.

Preparing to assemble pocket hole joints with screws and Titebond II Premium Wood Glue

Clamps to hold the joint together

Tools used to drill a pocket hole

A pocket hole used to reinforce a mite joint

Pocket hole to reinforce a butt joint

Joint Design

Dowel Joint

One of the most common joints used in assembly is the dowel joint. In the manufacture of a dowel joint, as with all glue joints, there is considerable difference between a well-made joint and one made under usual factory conditions. In designing for factory manufacture, the factor of safety should include "manufacturing variables".

This is illustrated experimentally by Rudolph Willard[1], who took three chairs assembled by a factory and the same number assembled in his laboratory. He then applied a back-and-forth tilting action as a destructive force. The factory assembled chairs averaged only 2,000 cycles while the laboratory assembled chairs averaged 50,000 cycles. This improved durability, from careful assembly, could be used to reflect a more delicate design with the same utility or with present design could achieve greater durability in the hands of the customer.

The strength of a simple dowel joint is limited by either (1) the tensile strength of the dowel or (2) the shear strength of the joint resulting from the exterior of the dowel glued to the interior of the hole; whichever is lower. Greater dowel length obviously increases the glue area and total strength of the glued joint. The effect of the greater dowel length is limited by the tensile strength of the dowel. With a given species and dowel diameter, increasing dowel length beyond this does not increase the tensile strength of the dowel.

Carl Eckelman[2] compared these two properties and found that with maple dowels the maximum effective dowel length for each common dowel diameter was:

Dowel Diameter	Dowel Length
¼"	2"
3/8"	3"
½"	3 ½"

He concludes that added strength is obtained by increasing dowel length up to a length-to-diameter ratio of 8:1 or 9:1.

Eckelman[3] further investigated the strength obtained with various relative locations of a two-dowel joint. The strength is directly related to (a) the strength from one of the dowels, (b) the distance between the dowel centers and (c) half the distance between the dowel center and the edge of the shoulder.

Expressed as a formula: **total bending strength** = strength of dowel joint for one dowel x (distance between the dowel centers + half the distance between the one dowel center and the edge of the shoulder). (Figure 7)

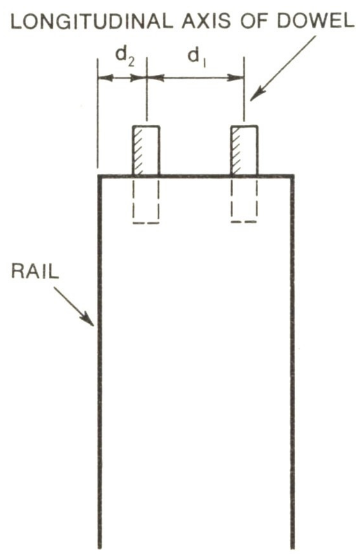


Figure 7: Values of d_1 and d_2 are measured as shown

Maximum strength is also obtained by maximizing the strength of each dowel by selection of wood species, diameter and length. Increasing the distance between the dowel centers is twice as effective as increasing the shoulder between the dowel center and the edge of the rail. The dowels cannot be placed so near the edge of the rail that it is cracked when the dowels are .driven in place.

In commenting on these results, Rudolph Willard[4] says, "'Unfortunately appearance design often limits seat rail width, sometimes…with a two-inch rail, 7/16" dowels, and 3/16" wood between hole and edge of rail, the distance between centers of dowels works out to 3/16". This is about the best you can do with a two-inch rail. But with a 2 1/2" rail, you could get a joint about 40% stronger."

"Some designers and merchandise men object to a wide, straight seat rail, but would accept one with the bottom edge bandsawn in some way that most of the rail would be narrow but it would flare out wider at the back end where the seat rail joins the back post.:" (Figure 8)

Figure 8: Chair with side rail flaired at ends to increase glue joint strength.

(1) Rudolph Williard, "Stronger Chair Joints – Part II" FURNITURE DESIGN AND MANUFACTURING, October 1964, page 72.
(2) Carl A. Eckelman, "Engineering Concepts of Single-Pin Dowel Joint Design" JOURNAL PAPER NUMBER 3671, Purdue University Agricultural Station, May 1969.
(3) Carl A. Eckelman, "Bending Strength and Movement – Rotational Characteristics of Two-Pin Movement – Resisting Dowel Joints" FOREST PRODUCTS JOURNAL, Volume 21, Number 3, page 35.
(4) Rudolph Williard, Ibid, page 213

Not only does variability of materials and workmanship affect the durability of a glued joint, but also the fatigue of the structure when subjected to cyclic stress. Carl Eckelman[5] pointed this out graphically (Figure 9). The applied load greatly affected joint strength. At 500-inch pounds, there was no failure, even after 10,000 cycles. Increasing load increased the fatigue until at 2,500-inch pounds, failure occurred in less than 1,000 cycles. 500-inch pounds are less than 1/6 of the ultimate joint strength. He suggests using a design load of 1,000-inch pounds, which withstood 200,000 cycles.

Stretchers greatly increase the stability of a chair. Carl Eckelman[6] remarks that "Stretchers and spindles are important structural elements in several types of furniture, but because of their relatively small size their contribution to the overall strength of a furniture frame is often overlooked. Stretchers actually perform a structural function in chairs that is disproportinate to their size.

By preventing the front leg and seat rail from rotating as a unit, they reduce the bending force acting on the seat rail to back post joint by about one-half and the chair is thereby greatly strengthened."

He concludes that "properly made turned pin joints are quite rigid and can develop the full bending strenght of stretchers and spindles of equal diameter or cross section. For ¾-inch square members turned to a ¾-inch pin on one end, it was shown that the pind had to be inserted at least ¾-inch into the post in order to develop the full strength of the stretcher. This is particularly important consideration. In a number of chairs the author has tested, stretcher and spindle ends were often inserted only ½-inch into other members when they could just as easily have been pressed in ¾ or even 1-inch. Several spindle back chairs in particular could have been greatly strengthened in this way at no extra cost."

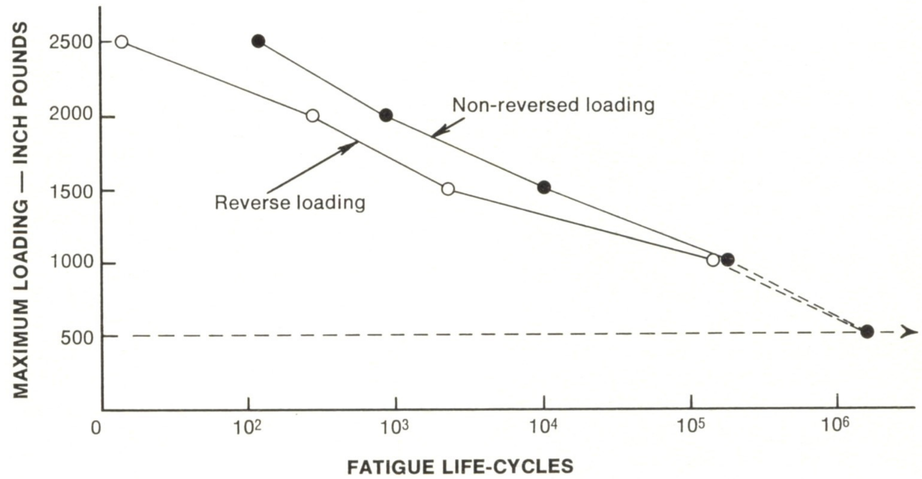


Figure 9: Graph showing relationship of load to cycles to failure

"Fianally, the magnitude of the bending strength of the stretchers and joints used in this study are of considerable interest. It may seem surprising but the bending strength of these ¾-inch turned pin joints were equal to the bending strength of the seat rail to back post joint in many commercially produced chairs! A side chair with a safety factor of 2.5 could in fact be constructed using a ¾-inch diameter rail and one ¾-inch diameter stretcher in each side frame."

Examples of furniture that could be made considerably stronger by the use of stretchers are illustrated. (Figures 10, 11, 12 and 13)

Several illustrations of designs using dowels which are too short follow. (Figures 14 and 15)

Figure 16 illustrates a table without stretchers which uses a decorative corner brace to reinforce the strength obtained from doweling the rail to the leg.

Commonly used types of dowels are the plain, spiral-cut and the fluted. (Figure 17)

Figure 10.

(5) Carl A. Eckelman, "The Fatigue Strength of Two-Pin Moment- Resisting Dowel Joints" Journal Paper #3965, Purdue University Agricultural Station.

(6) Carl A. Eckelman, "Chair Stretchers and Spindles Prove Tough After Purdue Testing" FURNITURE DESIGN AND MANUFACTURING, Septemeber 1970, page 200.

Figure 11.

Figure 14: The small cross-section of the table legs in these two examples does not allow adequate dowel length

Figure 12.

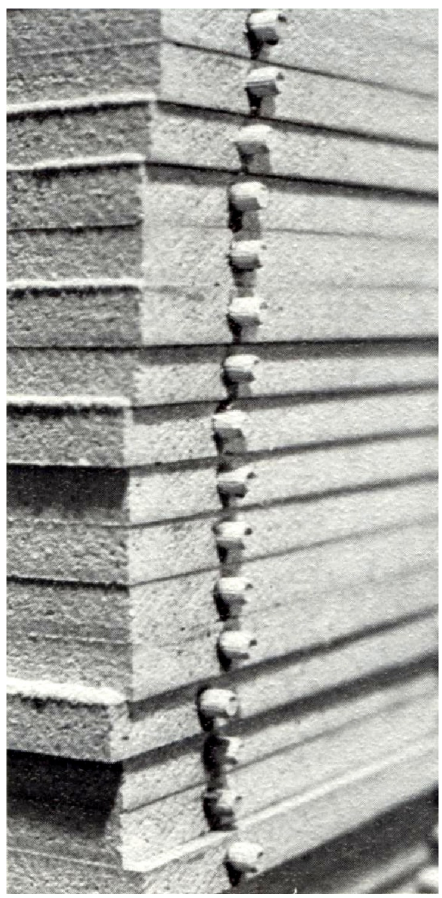


Figure 15.

Figure 13.

Figure 16.

Figure 17.

Mortise-and-Tenon

Another common assembly joint is the mortise-and-tenon. Michael Hill and Carl Eckleman[7] found that increasing the tenon length or width increased joint strength (Figure 18). A number of other factors affect the bending strength of the joint. Strength varies as 0.7 the wood shear strength (Figure 19). Tenon length has an effect as given by Figures 18 and 20. The particular adhesive has as effect on strength. Figure 21 points out that a 60% solids polyvinyl acetate may make a joint 32% stronger than a similar joint with phenol resorcinol adhesive. The same would be true of an aliphatic resin glue, a catalyzed polyvinyl acetate and a liquid polyurethane. The effectiveness of the adhesive is dependent on the joint fit. Figure 22 shows the effect of a loose fit.

The use of the above information suggests ways in which strength can be maximized within design limitations imposed by the external appearance of the furniture.

Gussets have some application in furniture pieces, such as in unpholstered furniture. Often joint quality in frame manufacturing tends to be poor, because the joints are covered. There are also certain places in the interior of case goods frames, where gussets would be beneficial.

Figure 18:
Effect of tenon strength, tenon width, wood species and adhesive on joint strength:

Rail Width (inches)	Tenon Width (inches)	Tenon Length (inches)	Glue[1]	Wood Species	Av. Actual Strength (in.-lbs.)
2.0	2.0	0.50	UF	Sugar Maple	1,727
"	"	0.75	"	"	2,832
"	"	1.00	"	"	3,540
"	"	1.50	"	"	4,536
"	"	2.00	"	"	5,889
3.0	0.5	1.00	PR	Sugar Maple	1,956
"	1.0	"	"	"	2,461
"	1.5	"	"	"	2,846
"	2.0	"	"	"	3,619
"	2.5	"	"	"	3,996
"	3.0	"	"	"	4,648
2.0	2.0	1.0	PR	Sugar Maple	3,105
2.0	2.0	1.0	PR	Yellow Poplar	2,009
"	"	"	"	Walnut	1,877
"	"	"	"	Red Oak	2,285
2.0	2.0	1.0	UF	Sugar Maple	3,859
"	"	"	PVA	"	4,121
"	"	"	LH	"	3,257

[1]UF = Urea Formaldehyde Adhesive
PR = Phenol-Resorcinol Adhesive
PVA = Polyvinyl Acetate Adhesive (60% solids)
LH = Animal Adhesive

Figure 19:
Shear strength of various wood species:

Wood Species	Shear Strength At 7% M.C. (psi)
Ash, white	1,587
Beech, American	2,312
Birch, White	1,392
Birch, Yellow	2,162
Hickory, Shagbark	2,795
Maple, Sugar	2,680
Maple, Silver	1,702
Oak, Red	2,047
Oak, White	2,300
Pine, Ponderosa	1,334
Poplar, Tulip	1,369
Sweetgum	1,840
Sycamore	1,691
Walnut, Black	1,576

Figure 20:
Effect of tenon length on mortise-and-tenon joints:

Tenon Length (inches)	Tenon Length Factor
0.500	0.48
0.625	0.68
0.750	0.80
0.875	0.90
1.000	1.00
1.125	1.06
1.250	1.12
1.375	1.20
1.500	1.28
1.625	1.36
1.750	1.46
1.875	1.56
2.000	1.66

Figure 21:
Relative effect of various adhesives on mortise-and-tenon joint strength:

Adhesive	Adhesive Factor
Phenol Resorcinol	1.00
Animal	1.05
Urea Formaldehyde	1.24
Polyvinyl Acetate (60% solids)	1.32

Figure 22:
Relative effect of tenon fit on mortise-and-tenon joints

Tenon Fit (inches)	Tenon Fit Factor
0.000 to 0.002	1.00
0.003 to 0.005	0.94
0.006 to 0.008	0.89

Tenon fit is defined as the difference between tenon thickness and mortise thickness.

(7) Michael D. Hill and Dr. Carl A. Eckelman, "Flexibility and Bending Strength of Mortise-and-Tenon Joints", Furniture Design and Manufacturing, December 1973.

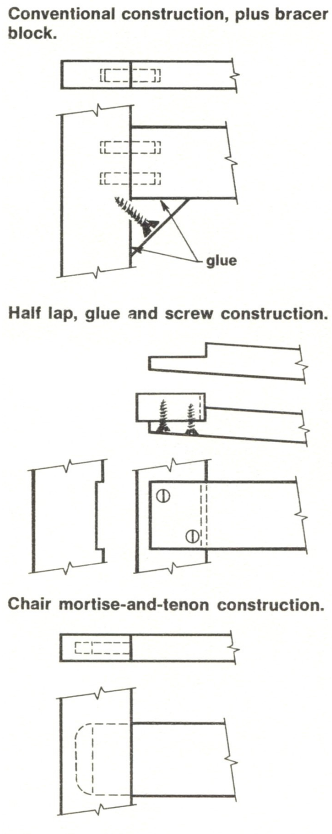
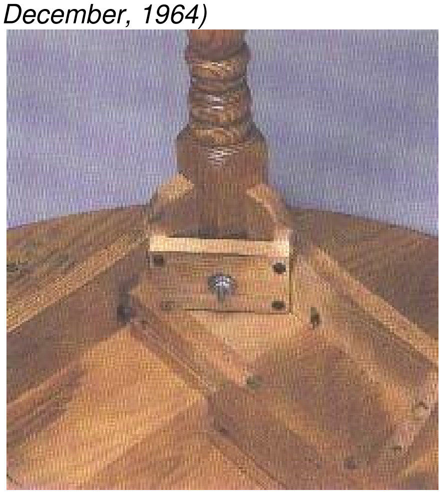


Figure 23: (Based on drawings by John Henderson, FURNITURE DESIGN & MANUFACTURING, December, 1964)



An example of the use of a corner block to strengthen the joint.

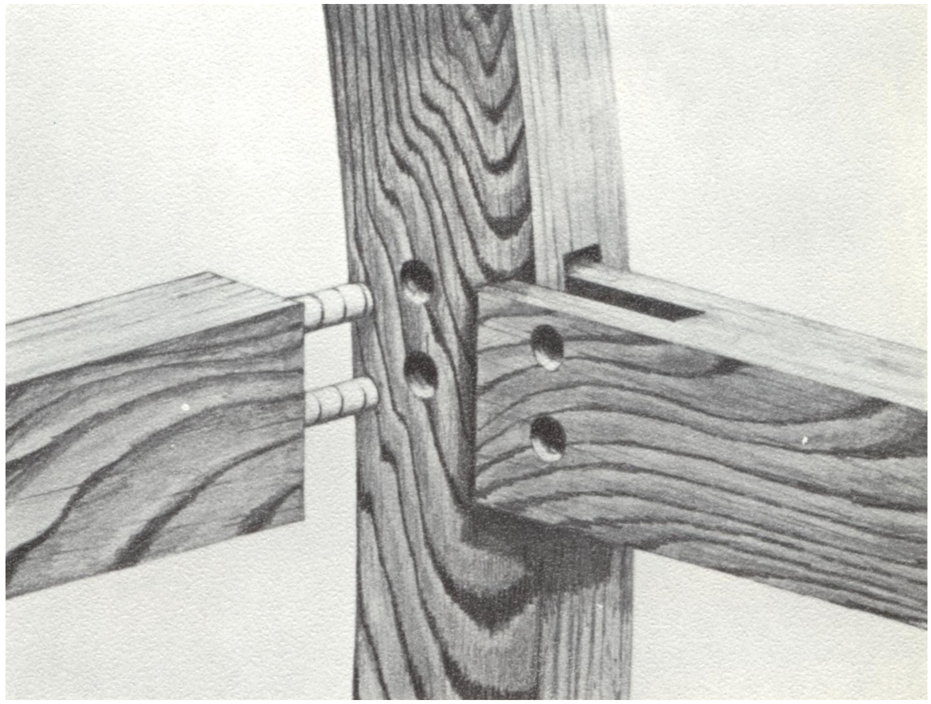


Figure 24: A chair construction utlizing dowels to lock in the mortise-and-tenon joint. (Courtesy Boling Chair Co., Siler City, NC)

Carl Eckleman[8] points out that (1) these gusset plate joints have high strength, (2) are readily fabricated, (3) perform reliably in service and are (4) easily inspected for quality. Joints with gussets are stronger than doweled or mortise-and-tenon joints. They can also be used to reinforce either of the above. In general, the larger the gusset, the stronger the joints.

In some instances of case goods construction, the gluing of a thin panel on the exterior of both the posts and stretchers will greatly increase the resistance of the case to racking. This is similar but superior to the use of four gussets in the same application.

Rudolph Willard[9] reported on three designs for chairs which improve their resistance to racking (Figure 23). The half lap joint “showed three and one half times the strength of conventional construction at proportional limit and five times the strength at failure”. The mortise-and-tenon joint pictured “showed one and one half times the strength of conventional construction at proportional limit and three and one-fourth times the strength at failure”. The latter construction does not change the external appearance of the chair. Figure 24 illustrates a commercial design, adding the shear strength of the dowels to the bending strength of the dowelled joint.

North Carolina State University developed a frame for an upholstered chair which utilizes the strength of the glue and wood to better advantage than conventional upholstery frames.

Rudolph Willard[10] disccussed the construction of this chaus (Figures 25 and 26) and the manufacturing methods to produce it.

(8) Dr. Carl A. Eckleman, “Designing Joints with Gusset Plaste”, Paper #4534
(9) Rudolph Willard, “Research Project Develops Stronger Chair Joints – Part II” FURNITURE DESIGN AND MANUFACTURING, December 1964, page 66.
(10) Rudolph Willard, “New Approach to Upholstered Frame Construction” FURNITURE DESIGN AND MANUFACTURING, January 1972, page 48.

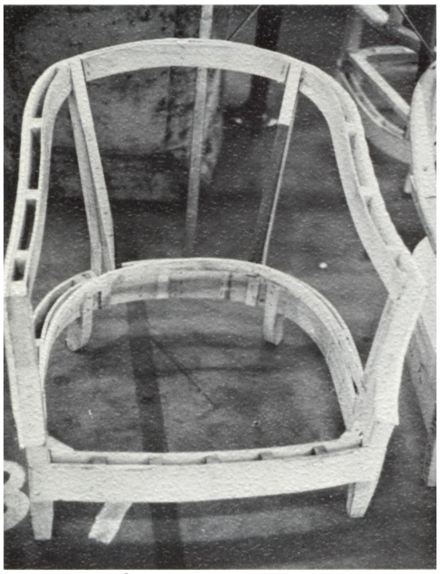


Figure 25: Clark chair developed at North Carolina University utilizing bent plywood

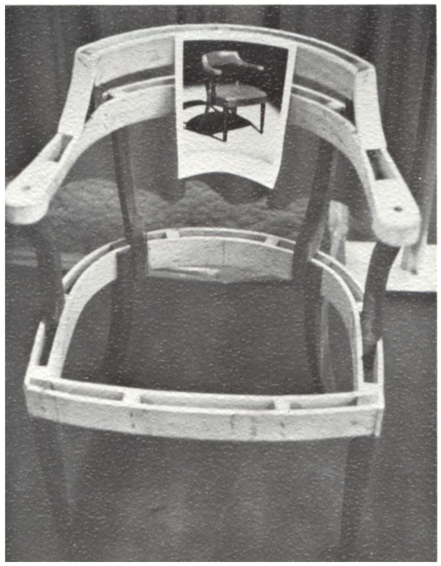


Figure 26: Clark chair (Figure 47) with show wood.

Looking at another construction detail, Carl Eckelman[11] found that larger corner blocks increased the bend strength of a glued joint.

Block Size	Wood Species	Average Bending Strength
2½	Yellow Poplar	641
2		502
1½		310
1		127
2½	Sweetgum	751
2		578
1½		367
1		190

(11) Dr. Carl A. Eckleman, “Shear and Bending Strength of Glued Corner Blocks” Paper 4747, Purdue University Agricultural Experiment Station.

Wood and Moisture Control

The Forest Products Laboratory discusses the relationship of wood and moisture control.[12]

(12) Quotations from WOOD HANDBOOK, Agricultural Handbook No. 72, The Forest Products Laboratory, Forest Service, U.S. Department of Agriculture, 1955, page 311-328.

Equilibrium Moisture Content

“Any piece of wood will give off or take on moisture from the surrounding atmosphere until the amount of moisture in the wood balances that in the atmosphere. The moisture content of the wood at the point of balance is called the equilibrium moisture content and is expressed as a percentage of the overn-dry weight of the wood.”

“Assuming constant temperature, the ultimate moisture content that a given piece of wood will retain depends entirely upon the relative humidity of the atmosphere surrounding it. The relationship between equilibrium moisture content and relative humidity at different temperatures is shown in (Figure 27).

For practical use in control of dry-kiln or storage-room conditions, comparartive values are shown for different dry-bulb temperatures and for different wet-bulb depressions. For example, a dry-bulb temperature of 70°F. and wet-bulb depression of 9° below dry-bulb temperature, which corresponds to a relative humidity of 59%, the equalibrium moisture content of the wood is 10.9%. Changes in relative humidity in the higher ranges cause greater changes in equilibrium moisture content than do corresponding changes in the lower ranges of relative humidity. Although different species exhibit some differences in their reactions to relative humidity, for practical purposes (Figure 27) applies to the wood of any species.”

TABLE OF EQUILIBRIUM MOISTURE CONTENT VALUES AT VARIOUS TEMPERATURES AND HUMIDITIES

Wet Bulb Lowering In Degrees Fahrenheit

Dry Bulb Temperature in Degrees Fahrenheit

	2	3	4	5	6	7	8	9	10	11	12	13	14	15
40	83 / 17.6	75 / 14.8	68 / 12.9	60 / 11.2	52 / 9.9	45 / 8.6	37 / 7.4	29 / 6.2	22 / 5.0	15 / 3.5	8 / 1.9			
45	85 / 18.3	78 / 15.6	72 / 13.7	64 / 12.0	58 / 10.7	51 / 9.5	44 / 8.5	37 / 7.5	31 / 6.5	25 / 5.3	19 / 4.2	12 / 2.9	6 / 1.5	
50	86 / 19.0	80 / 16.3	74 / 14.4	68 / 12.7	62 / 11.5	56 / 10.3	50 / 9.4	44 / 8.5	38 / 7.6	32 / 6.7	27 / 5.7	21 / 4.8	16 / 3.9	10 / 2.8
55	88 / 19.5	82 / 16.9	76 / 15.1	70 / 13.4	65 / 12.2	60 / 11.0	54 / 10.1	49 / 9.3	44 / 8.4	39 / 7.6	34 / 6.8	28 / 6.0	24 / 5.3	19 / 4.5
60	89 / 19.9	83 / 17.4	78 / 15.6	73 / 13.9	68 / 12.7	63 / 11.6	58 / 10.7	53 / 9.9	48 / 9.1	43 / 8.3	39 / 7.6	34 / 6.9	30 / 6.3	26 / 5.6
65	90 / 20.3	84 / 17.8	80 / 16.1	75 / 14.4	70 / 13.3	66 / 12.1	61 / 11.2	56 / 10.4	52 / 9.7	48 / 8.9	44 / 8.3	39 / 7.7	36 / 7.1	32 / 6.5
70	90 / 20.6	86 / 16.2	81 / 16.5	77 / 14.9	72 / 13.7	68 / 12.5	64 / 11.6	59 / 10.9	55 / 10.1	51 / 9.4	48 / 8.8	44 / 8.3	40 / 7.7	36 / 7.2
75	91 / 20.9	86 / 18.5	82 / 16.8	78 / 15.2	74 / 14.0	70 / 12.9	66 / 12.0	62 / 11.2	58 / 10.5	54 / 9.8	51 / 9.3	47 / 8.7	44 / 8.2	41 / 7.7
80	91 / 21.0	87 / 18.7	83 / 17.0	79 / 15.5	75 / 14.3	72 / 13.2	68 / 12.3	64 / 11.5	61 / 10.9	57 / 10.1	54 / 9.7	50 / 9.1	47 / 8.6	44 / 8.1
85	92 / 21.2	88 / 18.8	84 / 17.2	80 / 15.7	76 / 14.5	73 / 13.5	70 / 12.5	66 / 11.8	63 / 11.2	59 / 10.5	56 / 10.0	53 / 9.5	50 / 9.0	47 / 8.5
90	92 / 21.3	89 / 18.9	85 / 17.3	81 / 15.9	78 / 14.7	74 / 13.7	71 / 12.8	68 / 12.0	65 / 11.4	61 / 10.7	58 / 10.2	55 / 9.7	52 / 9.3	49 / 8.8
95	92 / 21.3	89 / 19.0	85 / 17.4	82 / 16.1	79 / 14.9	75 / 13.9	72 / 12.9	69 / 12.2	66 / 11.6	63 / 11.0	60 / 10.5	57 / 10.0	55 / 9.5	52 / 9.1
100	93 / 21.3	89 / 19.0	86 / 17.5	83 / 16.1	80 / 15.0	77 / 13.9	73 / 13.1	70 / 12.4	68 / 11.8	65 / 11.2	62 / 10.6	59 / 10.1	56 / 9.6	54 / 9.2
110	93 / 21.4	90 / 19.0	87 / 17.5	84 / 16.2	81 / 15.1	78 / 14.1	75 / 13.3	73 / 12.6	70 / 12.0	67 / 11.4	65 / 10.8	62 / 10.4	60 / 9.9	57 / 9.5
120	94 / 21.3	91 / 19.0	68 / 17.4	85 / 16.2	82 / 15.1	80 / 14.1	77 / 13.4	74 / 12.7	72 / 12.1	69 / 11.5	67 / 11.0	65 / 10.5	62 / 10.0	60 / 9.7
130	94 / 21.0	91 / 18.8	89 / 17.2	86 / 16.0	83 / 14.9	81 / 14.0	78 / 13.4	76 / 12.7	73 / 12.1	71 / 11.5	69 / 11.0	67 / 10.5	64 / 10.0	62 / 9.7
140	95 / 20.7	92 / 18.6	89 / 16.9	87 / 15.8	84 / 14.8	82 / 13.8	79 / 13.2	77 / 12.5	75 / 11.9	73 / 11.4	70 / 10.9	68 / 10.4	66 / 10.0	64 / 9.6
150	95 / 20.2	92 / 18.4	90 / 16.6	87 / 15.4	85 / 14.5	82 / 13.7	80 / 13.0	78 / 12.4	76 / 11.8	74 / 11.2	72 / 10.8	70 / 10.3	68 / 9.9	66 / 9.5
160	95 / 19.8	93 / 18.1	90 / 16.2	88 / 15.2	86 / 14.2	83 / 13.4	81 / 12.7	79 / 12.1	77 / 11.5	75 / 11.0	73 / 10.6	71 / 0.1	69 / 9.7	67 / 9.4
170	95 / 19.4	93 / 17.7	91 / 15.8	89 / 14.8	86 / 13.9	84 / 13.2	82 / 12.4	80 / 1.8	78 / 11.3	76 / 10.8	74 / 10.4	72 / 9.9	70 / 9.6	69 / 9.2

	16	17	18	19	20	21	22	23	24	25	26	27	28	29
40														
45														
50	5 / 1.5													
55	14 / 3.6	9 / 2.5	5 / 1.3											
60	21 / 4.9	17 / 4.1	13 / 3.2	9 / 2.3	5 / 1.3	1 / 0.2								
65	27 / 5.8	24 / 5.2	20 / 4.5	16 / 3.8	13 / 3.0	8 / 2.3	6 / 1.4	2 / 0.4						
70	33 / 6.6	29 / 6.0	25 / 5.5	22 / 4.9	19 / 4.3	15 / 3.7	12 / 2.9	9 / 2.3	6 / 1.5	3 / 0.7				
75	37 / 7.2	34 / 6.7	31 / 6.2	28 / 5.6	24 / 5.1	21 / 4.7	18 / 4.1	15 / 3.5	12 / 2.9	10 / 2.3	7 / 1.7	4 / 0.9	1 / 0.2	
80	41 / 7.7	38 / 7.2	35 / 6.8	32 / 6.3	29 / 5.8	26 / 5.4	23 / 5.0	20 / 4.5	18 / 4.0	15 / 3.5	12 / 3.0	10 / 2.4	7 / 1.8	5 / 1.1
85	44 / 8.1	41 / 7.6	38 / 7.2	36 / 6.7	33 / 6.3	30 / 6.0	28 / 5.6	25 / 5.2	23 / 4.8	20 / 4.3	18 / 3.9	15 / 3.4	13 / 3.0	11 / 2.4
90	47 / 8.4	44 / 8.0	41 / 7.6	39 / 7.2	36 / 6.8	34 / 6.5	31 / 6.1	29 / 5.7	26 / 5.3	24 / 4.9	22 / 4.6	19 / 4.2	17 / 3.8	15 / 3.3
95	49 / 8.7	46 / 8.2	44 / 7.9	42 / 7.5	39 / 7.1	37 / 6.8	34 / 6.4	32 / 6.1	30 / 5.7	28 / 5.3	26 / 5.1	23 / 4.8	22 / 4.4	20 / 4.0
100	51 / 8.9	49 / 8.5	46 / 8.1	44 / 7.8	41 / 7.4	39 / 7.0	37 / 6.7	35 / 6.4	33 / 6.1	30 / 5.7	28 / 5.4	26 / 5.2	24 / 4.9	22 / 4.6
110	55 / 9.2	52 / 8.8	50 / 8.4	48 / 8.1	46 / 7.7	44 / 7.5	42 / 7.2	40 / 6.8	38 / 6.6	36 / 6.3	34 / 6.0	32 / 5.7	30 / 5.4	28 / 5.2
120	58 / 9.4	55 / 9.0	53 / 8.7	51 / 8.3	49 / 7.9	47 / 7.7	45 / 7.4	43 / 7.2	41 / 6.8	40 / 6.6	38 / 6.3	36 / 6.1	34 / 5.8	33 / 5.6
130	60 / 9.4	58 / 9.0	56 / 8.7	54 / 8.3	52 / 8.0	50 / 7.8	48 / 7.6	47 / 7.3	45 / 7.0	43 / 6.8	41 / 6.6	40 / 6.4	38 / 6.1	37 / 5.9
140	62 / 9.4	60 / 9.0	58 / 8.7	56 / 8.4	54 / 8.0	53 / 7.8	51 / 7.6	49 / 7.3	47 / 7.1	46 / 6.9	44 / 6.6	43 / 6.4	41 / 6.2	40 / 6.0
150	64 / 9.2	62 / 8.9	60 / 8.6	58 / 8.3	57 / 8.0	55 / 7.8	53 / 7.5	51 / 7.3	49 / 7.1	48 / 6.9	46 / 6.7	45 / 6.4	43 / 6.2	42 / 6.0
160	65 / 9.1	64 / 8.8	62 / 8.5	60 / 8.2	58 / 7.9	57 / 7.7	55 / 7.4	53 / 7.2	52 / 7.0	50 / 6.8	49 / 6.7	47 / 6.4	46 / 6.2	44 / 6.0
170	67 / 9.0	65 / 8.6	63 / 8.4	62 / 8.0	60 / 7.8	59 / 7.6	57 / 7.3	55 / 7.2	53 / 6.9	52 / 6.7	51 / 6.6	49 / 6.4	48 / 6.2	47

TO USE CHART: Obtain wet and dry bulb readings. Subtract wet bulb reading from dry bulb reading. Find dry bulb on left margin of chart and follow across chart to column where figure at top corresponds with the difference between wet and dry readings. At point of intersection, the black figure gives relative humidity in percent and the red figure gives equilibrium moisture content.

THE FRANKLIN GLUE COMPANY
2020 BRUCK STREET
COLUMBUS, OHIO 43207

Figure 27

"Wood in service is exposed to daily and seasonal changes in relative humidity. Thus, wood is virtually always undergoing at least slight changes in moisture content because of its tendency to come to a balance with the relative humidity of the surrounding air. The changes are gradual and may be further retarded by protective coatings, such as varnish, lacquer or paint. The practical object of all correct seasoning, handling and storage methods is to minimize moisture content variations in wood in service by fabricating or installing the wood at a moisture content corresponding to the average atomospheric conditions to which it will be exposed."

Shrinkage of Wood

"Wood, like many other materials, shrinks as it loses moisture and swells as it absorbs moisture."

"Wood from the tree may contain from 30 to 300 percent of water, based on the weight of oven-dry wood. This water may be separated roughly into two parts, that contained as free water in cell cavities and intercellular spaces of the wood and that held as absorbed water in the capillaires of the walls of such wood elelments as fibers and ray cells. The absorbed water is of primary interest in the consideration of shrinkage. When all of the free water is removed but all of the absorbed water remains, wood is said to have reached the fiber saturation point. The fiber saturation point is approximately 30% moisture content for all species."

"Shrinkage occurs if the moisture content is reduced to a value below that of the fiber saturation point and is proportional to the amound of moisture lost below 30% moisture content. Wood dried to 15% moisture content has attained about one-half of the total shrinkage possible. For each one percent loss in moisture content below the fiber saturation point, the wood shrinks about one-thirtieth of the total. Likewise, for each one percent increase in moisture content the piece swells about one-thirtieth of the total swelling possible. The total swelling is equal numberically to the totak shrinkage. Shrinking and swelling are expressed as percentages based on the gree dimensions of wood."

"As a piece of wood dries, the outer parts are reduced to a moisture content below the fiber saturation point considerably sooner than the inner parts. Thus, the whole piece may show some shrinkage before the average moisture content reaches the fiber saturation point."

Wood shinks most in the direction of the annual growth rings (tangentially), somewhat less across these rings (radially), and very little, as a rule, along the grain (longitudinally). The combined effects of radial and tangential shrinkage on the shape of various sections in drying from the green conditions are illustrated in (Figure 28). Wood that contains crossgrain or irregular grain will shrink more longitudinally than straight-grained wood. Local shrinkage in such pieces may cause distortions."

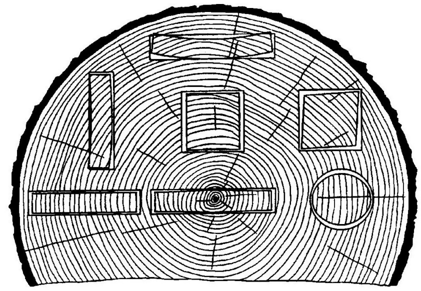
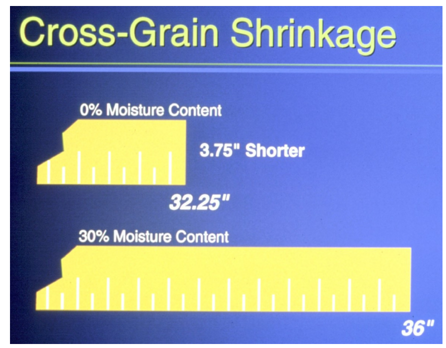
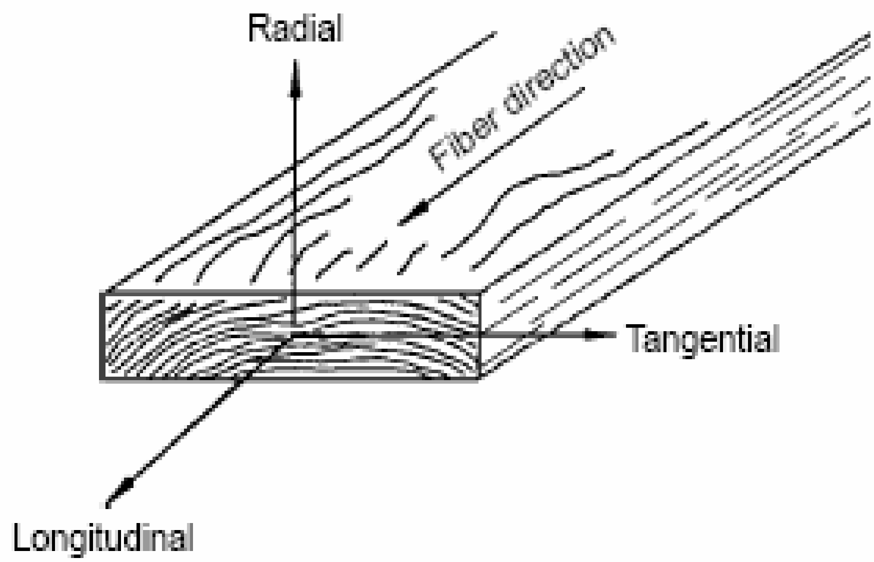


Figure 28: Characteristic shrinkage and distortion of flats, squares, and rounds as affected by the direction of the annual rings. Tangential shrinkage is about twice as great as radial.





Three principle axis of wood with respect to grain direction and growth rings
(*From "Wood Handbook", General Technical Report 113, U.S. Department o Agriculature)*

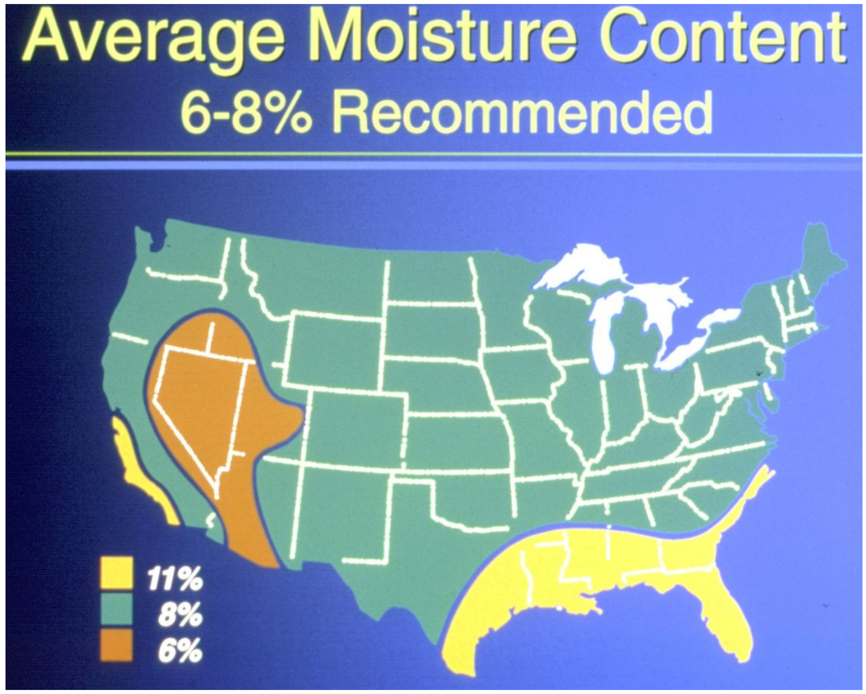


Figure 29: Recommended moisture content averages for interior-finishing woodwork for use in various parts of the United States

"In general the heavier species of wood shrink more across the grain than lighter ones. Heavier pieces also shrink more than lighter pieces of the same species. Hardwoods generally shrink more than softwoods. Species, however, do not always conform to the general shrinkage pattern. For example, basswood is a light wood but shrinks considerably more than black locust, a heavy wood.

"The total longitudinal shrinkage of normal wood usually ranges from 0.1 to 0.3 percent of the green dimension. Exceptionally lightweight wood of any species tends to shrink abnormally in length."

Wood for Interior Service

"The moisture content requirements for finish lumber of wood products used inside heated buildings are more exacting than those for lumber used outdoors or in unheated buildings. This is due to the higher character of the service required and also to the lower relative humidity conditions encountered within heated buildings than outdoors. (Figure 29 and 30) show the recommended moisture content values and tolerances for wood used in interior parts of heated buildings. The values for exterior trim and siding can be applied to lumber used outdoors and in unheated buildings. (Figure 30) also gives Corresponding values for exterior parts of heated buildings."

"General commercial practice is to kiln-dry some wood products, such as furniture wood, to a slightly lower moisture content than service conditions demand, counting on a moderate increase in moisture content during the storage and manufacturing periods. This practice is intended to assure unifrom distribution of moisture among the individual pieces." The moisture content of lumber for furniture manufacture should not exceed 8%.

Changing wood species may improve or degrade the strength and durability of a piece of furniture due to the difference in inherent strength of the species of wood.

	Recommended moisture content (%) in various climatological regions					
	Most areas of the United States		Dry southwestern area[a]		Damp, warm coastal area[a]	
Use of wood	Average[b]	Individual pieces	Average[b]	Individual pieces	Average[b]	Individual pieces
Interior: woodwork, flooring, furniture, wood trim	8	6–10	6	4–9	11	8–13
Exterior: siding, wood trim, sheathing, laminated timbers	12	9–14	9	7–12	12	9–14

[a]Major areas are indicated in Figure 12–1.
[b]To obtain a realistic average, test at least 10% of each item. If the quantity of a given item is small, make several tests. For example, in an ordinary dwelling having about 60 floor joists, at least 10 tests should be made on joists selected at random.

Figure 30. (From "Wood Handbook", General Technical Report 113, U.S. Department of Agriculture)

The foregoing discussion can be quite helpful in avoiding trouble by proper selection of species and joint design. Because of the relative dimensional change between longitudinal and tangetial directions, it is unwise to expect a flush joint joining the two to remain flush with the traditional mosure change, This is important not only at junctures of individual parts (Figure 31) but also in assemblues, such as panels glued within lumber frames (Figures 32, 33 and 34) or veneering a lumber core without crossband (Figure 35).

Figure 33a and 33b shows not only the variations in dimensional change between species but also between radial and tangential directions. Beech shrinks more than twice as much tangentially as radially. Edge gluing both types of boards in an assembly will cause waves to occur as the moisture changes.

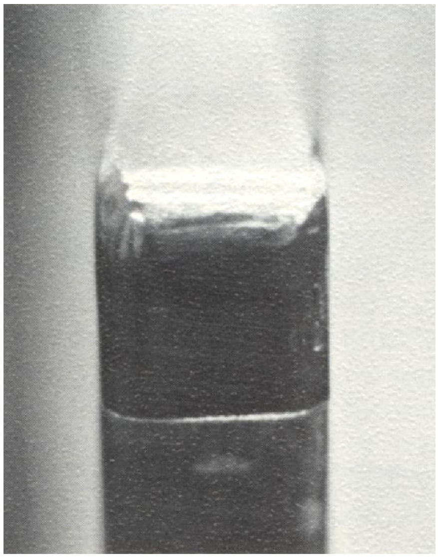


Figure 31: Chair stump has swelled beyond the arm.

Figure 32: Panel split from restraint of glued lunber edge band

Figure 33: New lumber-banded panel used for a tabletop may rupture with aging.

Figure 33b: Notice the tabletop above has dowels to further stabilize the assembly

Figure 34: An antique mantel that shows shrinjage of the wood in the mitered joints

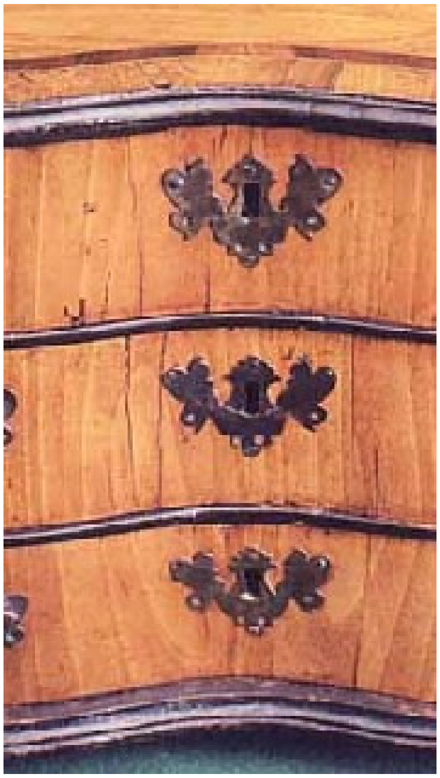


Figure 35: An example of veneer splitting over a wooden core

Shrinkage values of domestic woods

Species	Shrinkage[a] (%) from green to ovendry moisture content: Radial	Tangential	Volumetric
Hardwoods			
Alder, red	4.4	7.3	12.6
Ash			
Black	5.0	7.8	15.2
Blue	3.9	6.5	11.7
Green	4.6	7.1	12.5
Oregon	4.1	8.1	13.2
Pumpkin	3.7	6.3	12.0
White	4.9	7.8	13.3
Aspen			
Bigtooth	3.3	7.9	11.8
Quaking	3.5	6.7	11.5
Basswood, American	6.6	9.3	15.8
Beech, American	5.5	11.9	17.2
Birch			
Alaska paper	6.5	9.9	16.7
Gray	5.2	—	14.7
Paper	6.3	8.6	16.2
River	4.7	9.2	13.5
Sweet	6.5	9.0	15.6
Yellow	7.3	9.5	16.8
Buckeye, yellow	3.6	8.1	12.5
Butternut	3.4	6.4	10.6
Cherry, black	3.7	7.1	11.5
Chestnut, American	3.4	6.7	11.6
Cottonwood			
Balsam poplar	3.0	7.1	10.5
Black	3.6	8.6	12.4
Eastern	3.9	9.2	13.9
Elm			
American	4.2	9.5	14.6
Cedar	4.7	10.2	15.4
Rock	4.8	8.1	14.9
Slippery	4.9	8.9	13.8
Winged	5.3	11.6	17.7
Hackberry	4.8	8.9	13.8
Hickory, true			
Mockernut	7.7	11.0	17.8
Pignut	7.2	11.5	17.9
Shagbark	7.0	10.5	16.7
Shellbark	7.6	12.6	19.2
Holly, American	4.8	9.9	16.9
Honeylocust	4.2	6.6	10.8
Locust, black	4.6	7.2	10.2
Madrone, Pacific	5.6	12.4	18.1
Magnolia			
Cucumbertree	5.2	8.8	13.6
Southern	5.4	6.6	12.3
Sweetbay	4.7	8.3	12.9
Maple			
Bigleaf	3.7	7.1	11.6
Black	4.8	9.3	14.0
Red	4.0	8.2	12.6
Silver	3.0	7.2	12.0
Striped	3.2	8.6	12.3
Sugar	4.8	9.9	14.7
Oak, red			
Black	4.4	11.1	15.1
Laurel	4.0	9.9	19.0
Northern red	4.0	8.6	13.7
Pin	4.3	9.5	14.5
Scarlet	4.4	10.8	14.7
Southern red	4.7	11.3	16.1
Water	4.4	9.8	16.1
Willow	5.0	9.6	18.9
Oak, white	4.4	8.8	12.7
Bur	5.3	10.8	16.4
Oak, white—con.			
Chestnut			
Live	6.6	9.5	14.7
Overcup	5.3	12.7	16.0
Post	5.4	9.8	16.2
Swamp, chestnut	5.2	10.8	16.4
White	5.6	10.5	16.3
Persimmon, common	7.9	11.2	19.1
Sassafras	4.0	6.2	10.3
Sweetgum	5.3	10.2	15.8
Sycamore, American	5.0	8.4	14.1
Tanoak	4.9	11.7	17.3
Tupelo			
Black	5.1	8.7	14.4
Water	4.2	7.6	12.5
Walnut, black	5.5	7.8	12.8
Willow, black	3.3	8.7	13.9
Yellow-poplar	4.6	8.2	12.7
Softwoods			
Cedar			
Yellow	2.8	6.0	9.2
Atlantic white	2.9	5.4	8.8
Eastern redcedar	3.1	4.7	7.8
Incense	3.3	5.2	7.7
Northern white	2.2	4.9	7.2
Port-Orford	4.6	6.9	10.1
Western redcedar	2.4	5.0	6.8
Douglas-fir,			
Coast[b]	4.8	7.6	12.4
Interior north[b]	3.8	6.9	10.7
Interior west[b]	4.8	7.5	11.8
Fir			
Balsam	2.9	6.9	11.2
California red	4.5	7.9	11.4
Grand	3.4	7.5	11.0
Noble	4.3	8.3	12.4
Subalpine	2.6	7.4	9.4
White	3.3	7.0	9.8
Hemlock			
Eastern	3.0	6.8	9.7
Mountain	4.4	7.1	11.1
Western	4.2	7.8	12.4
Larch, western	4.5	9.1	14.0
Pine			
Eastern white	2.1	6.1	8.2
Jack	3.7	6.6	10.3
Loblolly	4.8	7.4	12.3
Lodgepole	4.3	6.7	11.1
Longleaf	5.1	7.5	12.2
Pitch	4.0	7.1	10.9
Pond	5.1	7.1	11.2
Ponderosa	3.9	6.2	9.7
Red	3.8	7.2	11.3
Shortleaf	4.6	7.7	12.3
Slash	5.4	7.6	12.1
Sugar	2.9	5.6	7.9
Virginia	4.2	7.2	11.9
Western white	4.1	7.4	11.8
Redwood			
Old growth	2.6	4.4	6.8
Young growth	2.2	4.9	7.0
Spruce			
Black	4.1	6.8	11.3
Engelmann	3.8	7.1	11.0
Red	3.8	7.8	11.8
Sitka	4.3	7.5	11.5
Tamarack	3.7	7.4	13.6

[a]Expressed as a percentage of the green dimension.
[b]Coast type Douglas-fir is defined as Douglas-fir growing in the States of Oregon and Washington west of the summit of the Cascade Mountains. Interior West includes the State of California and all counties in Oregon and Washington east of but adjacent to the Cascade summit. Interior North includes the remainder of Oregon and Washington and the States of Idaho, Montana, and Wyoming.

(*From "Wood Handbook", General Technical Report 113, U.S. Department o Agriculature)*

Figure 36a

Shrinkage for some woods imported into the United States[a]

Species	Shrinkage[b] from green to ovendry moisture content (%) Radial	Tangential	Volumetric	Location[c]	Species	Shrinkage[b] from green to ovendry moisture content (%) Radial	Tangential	Volumetric	Location[c]
Afrormosia (*Pericopsis elata*)	3.0	6.4	10.7	AF	Lauan, white (*Pentacme contorta*)	4.0	7.7	11.7	AS
Albarco (*Cariniana* spp.)	2.8	5.4	9.0	AM	Limba (*Terminalia superba*)	4.5	6.2	10.8	AF
Andiroba (*Carapa guianensis*)	3.1	7.6	10.4	AM	Macawood (*Platymiscium* spp.)	2.7	3.5	6.5	AM
Angelin (*Andira inermis*)	4.6	9.8	12.5	AM	Mahogany, African (*Khaya* spp.)	2.5	4.5	8.8	AF
Angelique (*Dicorynia guianensis*)	5.2	8.8	14.0	AM	Mahogany, true (*Swietenia macrophylla*)	3.0	4.1	7.8	AM
Apitong (*Dipterocarpus* spp.)	5.2	10.9	16.1	AS	Manbarklak (*Eschweilera* spp.)	5.8	10.3	15.9	AM
Avodire (*Turreanthus africanus*)	4.6	6.7	12.0	AF	Manni (*Symphonia globulifera*)	5.7	9.7	15.6	AM
Azobe (*Lophira alata*)	8.4	11.0	17.0	AM	Marishballi (*Licania* spp.)	7.5	11.7	17.2	AM
Balata (*Manilkara bidentata*)	6.3	9.4	16.9	AM	Meranti, white (*Shorea* spp.)	3.0	6.6	7.7	AS
Balsa (*Ochroma pyramidale*)	3.0	7.6	10.8	AM	Meranti, yellow (*Shorea* spp.)	3.4	8.0	10.4	AS
Banak (*Virola* spp.)	4.6	8.8	13.7	AM	Merbau (*Intsia bijuga* and *I. palembanica*)	2.7	4.6	7.8	AS
Benge (*Guibourtia arnoldiana*)	5.2	8.6	13.8	AF	Mersawa (*Anisoptera* spp.)	4.0	9.0	14.6	AS
Bubinga (*Guibourtia* spp.)	5.8	8.4	14.2	AF	Mora (*Mora* spp.)	6.9	9.8	18.8	AM
Bulletwood (*Manilkara bidentata*)	6.3	9.4	16.9	AM	Obeche (*Triplochiton scleroxylon*)	3.0	5.4	9.2	AF
Caribbean pine (*Pinus caribaea*)	6.3	7.8	12.9	AM	Ocota pine (*Pinus oocarpa*)	4.6	7.5	12.3	AM
Cativo (*Prioria copaifera*)	2.4	5.3	8.9	AM	Okoume (*Aucoumea klaineana*)	4.1	6.1	11.3	AF
Ceiba (*Ceiba pentandra*)	2.1	4.1	10.4	AM	Opepe (*Nauclea* spp.)	4.5	8.4	12.6	AF
Cocobolo (*Dalbergia retusa*)	2.7	4.3	7.0	AM	Ovangkol (*Guibourtia ehie*)	4.5	8.2	12	AF
Courbaril (*Hymenaea courbaril*)	4.5	8.5	12.7	AM	Para-angelium (*Hymenolobium excelsum*)	4.4	7.1	10.2	AM
Cuangare (*Dialyanthera* spp.)	4.2	9.4	12.0	AM	Parana pine (*Araucaria angustifolia*)	4.0	7.9	11.6	AS
Degame (*Calycophyllum candidissimum*)	4.8	8.6	13.2	AM	Pau Marfim (*Balfourodendron riedelianum*)	4.6	8.8	13.4	AM
Determa (*Ocotea rubra*)	3.7	7.6	10.4	AM	Peroba de campos (*Paratecoma peroba*)	3.8	6.6	10.5	AM
Ebony, East Indian (*Diospyros* spp.)	5.4	8.8	14.2	AS	Peroba Rosa (*Aspidosperma* spp.)	3.8	6.4	11.6	AM
Ebony, African (*Diospyros* spp.)	9.2	10.8	20.0	AF	Piquia (*Caryocar* spp.)	5.0	8.0	13.0	AM
Ekop (*Tetraberlinia tubmaniana*)	5.6	10.2	15.8	AF	Pilon (*Hyeronima* spp.)	5.4	11.7	17.0	AM
Gmelina (*Gmelina arborea*)	2.4	4.9	8.8	AS	Primavera (*Cybistax donnell-smithii*)	3.1	5.1	9.1	AM
Goncalo alves (*Astronium graveolens*)	4.0	7.6	10.0	AM	Purpleheart (*Peltogyne* spp.)	3.2	6.1	9.9	AM
Greenheart (*Ocotea rodiaei*)	8.8	9.6	17.1	AM	Ramin (*Gonystylus* spp.)	4.3	8.7	13.4	AS
Hura (*Hura crepitans*)	2.7	4.5	7.3	AM	Roble (*Quercus* spp.)	6.4	11.7	18.5	AM
Ilomba (*Pycnanthus angolensis*)	4.6	8.4	12.8	AF	Roble (*Tabebuia* spp. Roble group)	3.6	6.1	9.5	AM
Imbuia (*Phoebe porosa*)	2.7	6.0	9.0	AM	Rosewood, Brazilian (*Dalbergia nigra*)	2.9	4.6	8.5	AM
Ipe (*Tabebuia* spp.)	6.6	8.0	13.2	AM	Rosewood, Indian (*Dalbergia latifolia*)	2.7	5.8	8.5	AS
Iroko (*Chlorophora excelsa* and *C. regia*)	2.8	3.8	8.8	AF	Rubberwood (*Hevea brasiliensis*)	2.3	5.1	7.4	AM
Jarrah (*Eucalyptus marginata*)	7.7	11.0	18.7	AS	Sande (*Brosimum* spp. Utile group)	4.6	8.0	13.6	AM
Jelutong (*Dyera costulata*)	2.3	5.5	7.8	AS	Sapele (*Entandrophragma cylindricum*)	4.6	7.4	14.0	AF
Kaneelhart (*Licaria* spp.)	5.4	7.9	12.5	AM	Sepetir (*Pseudosindora* spp. and *Sindora* spp.)	3.7	7.0	10.5	AS
Kapur (*Dryobalanops* spp.)	4.6	10.2	14.8	AS	Spanish-cedar (*Cedrela* spp.)	4.2	6.3	10.3	AM
Karri (*Eucalyptus diversicolor*)	7.8	12.4	20.2	AS	Sucupira (*Diplotropis purpurea*)	4.6	7.0	11.8	AM
Kempas (*Koompassia malaccensis*)	6.0	7.4	14.5	AS	Teak (*Tectona grandis*)	2.5	5.8	7.0	AS
Keruing (*Dipterocarpus* spp.)	5.2	10.9	16.1	AS	Wallaba (*Eperua* spp.)	3.6	6.9	10.0	AM
Lauan, light red and red (*Shorea* spp.)	4.6	8.5	14.3	AS					
Lauan, dark red (*Shorea* spp.)	3.8	7.9	13.1	AS					

[a]Shrinkage values were obtained from world literature and may not represent a true species average.
[b]Expressed as a percentage of the green dimension.
[c]AF is Africa; AM is Tropical America; AS is Asia and Oceania.

(*From "Wood Handbook", General Technical Report 113, U.S. Department o Agriculture)*

Figure 36b

Beech shrinks 0.54% for each one percent moisture change, while mahogany shrinks to half as much. This means that mahogany has much greater stability of dimension with mositure change than beech.

The gluing of materials with different coefficients of expansion with moisture or temperature change may cause problems. In some cases, this will be of sufficient disruptive force to break the bond. In other constructions it will only distract from appearance (Figure 37). The telegraphing may have been due to excessive clamp pressure, different moisture contents of the lumber band and the veneer. The use of a cross band or a heavier veneer might have corrected this condition.

Components being glued must have sufficient strength to withstand the stresses involved in use. Figure 38 shows two pine bedpost ball finials using pine dowels. Although there was considerable wood failure, the strength of the pine dowels limited the strength of the joint. Larger or longer dowels and/or different wood species would have improved strength.

Figure 36c:

Dimensional change of various wood species with change of moisture content.

	% Dimensional Change per % Moisture Change		
Species	**Radial**	**Tangential**	**Volumetric**
Alder, red	.15	.24	.49
Ash, white	.16	.26	.45
Basswood, American	.22	.31	.53
Beech, American	.17	.37	.54
Birch, yellow	.24	.31	.56
Cherry, black	.12	.24	.38
Cherry, Pin	.09	.34	.43
Cottonwood	.13	.31	.47
Elm, American	.14	.32	.49
Elm, Rock	.16	.27	.47
Elm, Slippery	.16	.30	.46
Hackberry	.16	.30	.56
Hickory, Pecan	.16	.30	.45
Luan, red	.11	.27	.39
Mahogany	.12	.17	.27
Maple, silver	.10	.24	.40
Maple, sugar	.16	.32	.50
Oak, black	.15	.32	.47
Oak, bur	.15	.29	.42
Oak, Southern Red	.15	.29	.54
Oak, white	.18	.30	.53
Sweetgum	.17	.33	.50
Sycamore, American	.17	.25	.47
Teak	.08	.14	.23
Tupelo, black	.15	.26	.46
Tupelo, water	.14	.25	.42
Walnut, black	.18	.26	.43
Willow, black	.09	.27	.48
Willow, Pacific	.10	.30	.46
Poplar, yellow	.13	.24	.41

From "Wood Handbook", Handbook No. 72, U. S. Department of Agriculture.

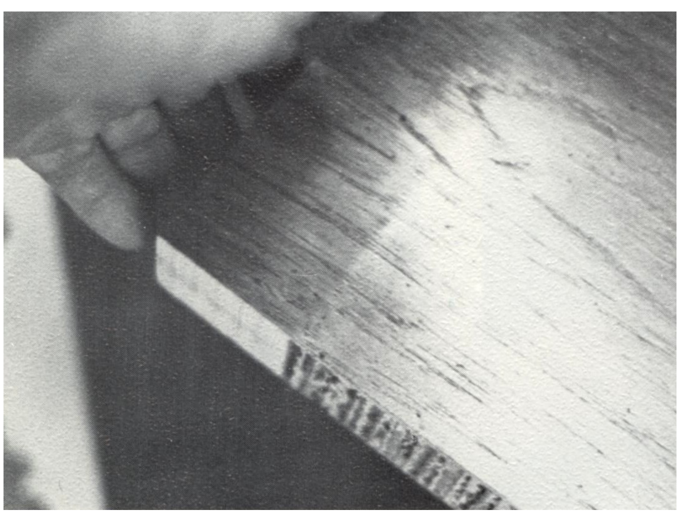


Figure 37: Junction of paper honeycomb and lumber bad telegraphed through surface veneer

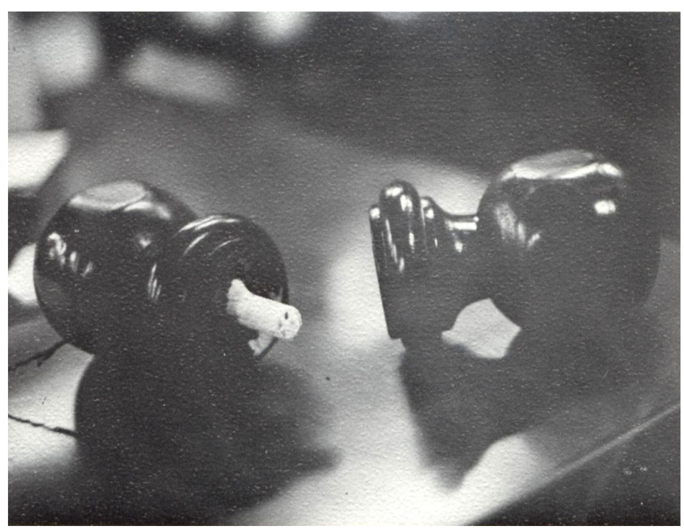


Figure 38: Bed post finials

In Figure 39, the table base was glued to a veneered panel. The face veneer evidently had little or no bond to the rest of the top. When a racking force was applied to the table, the bond between it and the rest of the plywood failed.

Some types of bonds are difficult to machine accurately enough to get a thin glue line. Such a joint is the triple miter as used in a parson's table or as in the table in Figure 40 and 41.

Other joints are difficult to apply adequate clamping pressure to make a strong joint. The back of the captain's chair in Figure 42 shows a design which is easily and adequately pressed to the end of the joint. Figure 43 illustrates a design where sufficient pressure is difficult to obtain at the end of the joint. A crack in the finish indicates movement resulting from a weak glue joint at this point.

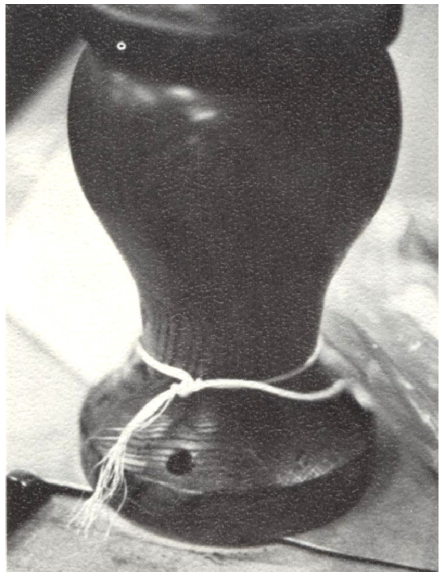


Figure 39: Central table post glued and screwed to veneer, which was poorly glued to remainder of plywood

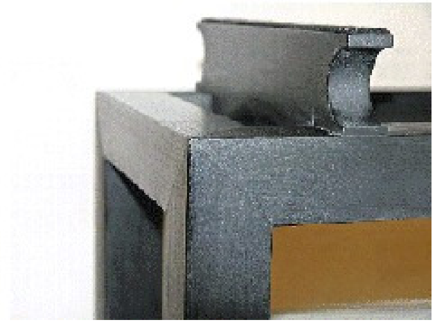


Figure 40: Three-way miter joint assembled

Figure 41: Pieces of the three-way miter joint above, before assembly or finishing.

Figure 42: Two examples of designs for the back of a captain's chair that allows proper clamping of the joint

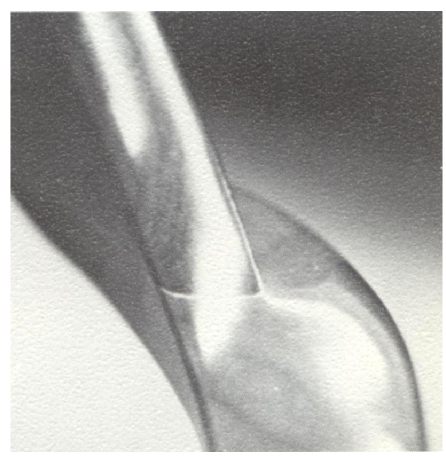


Figure 43: Close-up of back of captain's chair whose design did not allow for proper clamping

In many cases a change of design will also provide a better or greater gluing surface. An alternate to the arm on the top of the post shown in Figure 54 could be a miter (Figure 44). A joint such as Figure 45 may be used for greater strength.

Greater areas for doweling and gluing are provided by designs such as Figure 46 and 47.

A corner joint can be improved in strength by increasing the joint area, which will add strength, such as this through tenon joint (Figure 48).

Since wood pores saturated with adhesive do not accept stains and finish as does plain wood, glue spots show up under the finish. This may be due in some cases to sloppy workmanship. It may also occur if the design cuts through a glue line at a low angle. The glue line can be colored and/or should be cut through at right angles to minimize this problem. Glossy finishes will tolerate less defects from glue line problems than will matte finishes. Such things as sunken glue lines in substrates, dirt between the substrates and finished surface, unequal shrinkage or flushness will be accentuated by a gloss finish.

Figure 44: A miter joint to connect the rail and stump of a chair

Figure 45: A mitered mortise-and-tenon joint to connect the rail and stump of a chair

Figure 46: Arm and stump of a chair which improves the design of the glue joint

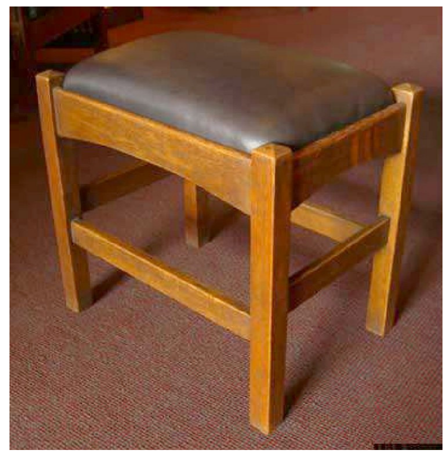


Figure 47: Method of attaching legs to a stool

Figure 48: Method of attaching leg to rails of a table

The concept of using PVC films as a hinge to fold a PVC covered substrate into a box has been expanded. Now, by using a V-groove to form joints, different shapes with many different substrate covers can be used. PVC, melamine, HPL (high pressure laminate), solid wood, wood veneered cores and vinyl can be used. Figure 49 is a sample of such construction and Figure 50 illustrates some of the configurations that can be used.

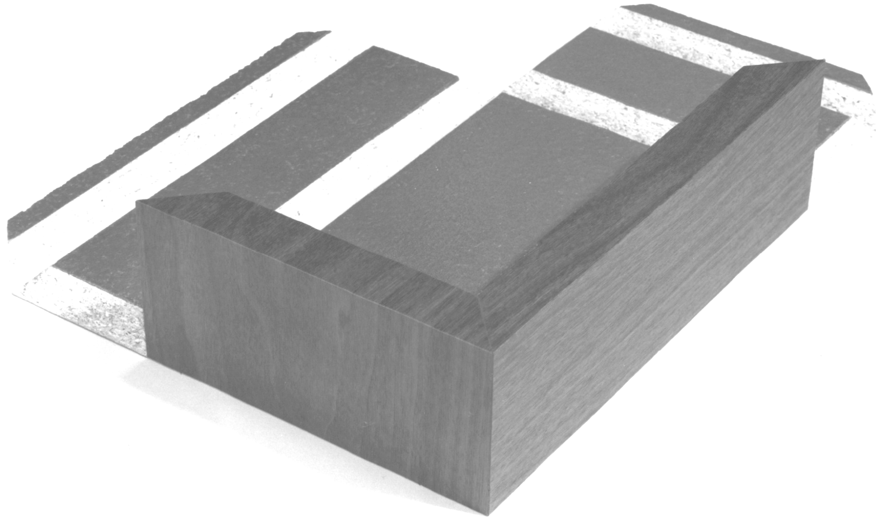
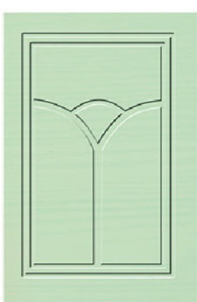


Figure 49: V-groove construction example

Figure 50: Examples of configurations that can be used by V-grooving the substrate



PVC over HDF

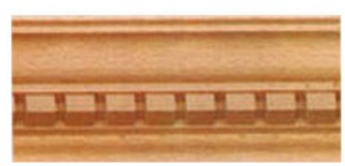
PVC foil pressed over MDF

Many decorative surfaces in furniture, simulationg fancy carved parts, are made from plastic of varying kinds, foams, urethanes or HPL. They may be formed by injection molding, extruding, casting or thermo-forming from sheet stock. Most are attached to wood, OSB or MDF cores by gluing. Since many parts may not fit as well as conventional wood parts, a high viscosity adhesive or mastic may be necessary for gap filling. Conventional wood adhesives do not adhere well to some of these substrates, so good bonds must be made with glues which have good adhesion to these materials.

Proper desing combined with good joint preparation, good gluing procedures and a quality adhesive can result in furniture which will delight the purchaser. Frequently, good design can be as inexpensive and pleasing as poor design.

Veneered panels

Metal-faced plywood



Veneer over fir

GLUING and FURNITURE DESIGN

Gluing is much more than an art; it is a science and is becoming more so every day. Not only the manufacture of adhesive products but of equal importance their application.

In the construction of any furniture from the lowest quality to the highest the selection and the use of the correct glue in the correct manner is of extreme importance. The correct glue used properly is always the least expensive.

This manual has been prepared and is presented to help you. We hope that it accomplishes its purpose. It represents many years of experience and many hours of concentrated study and careful testing.

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