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The Serpentine End-Matched Joint: Evaluating Strength and Stability

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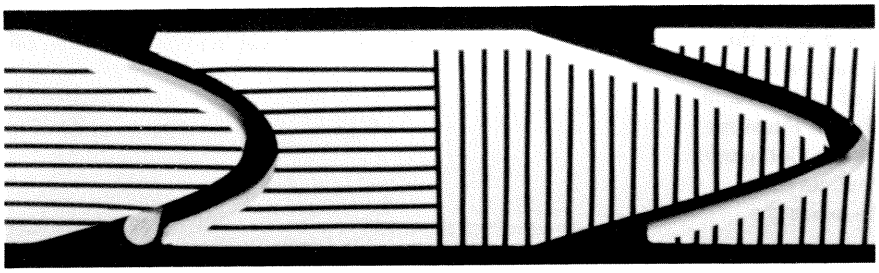

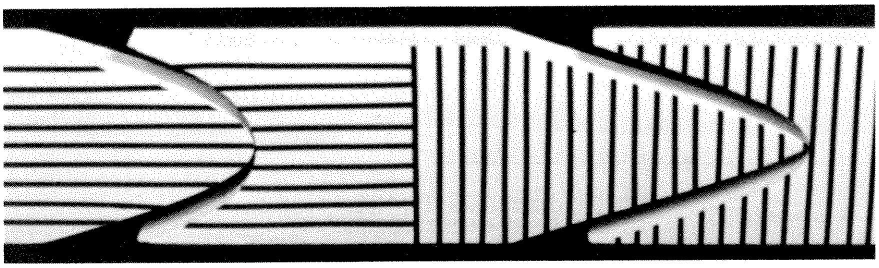

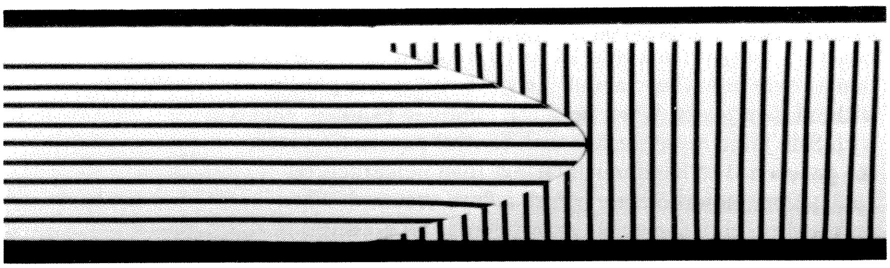

The Authors

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Abstract

The Serpentine end-matched (Sem) joint is a precisely machined butt joint with a sine wave shape. The joint is not readily visible to the eye and performs well in panels made of sugar maple, red oak, black walnut, and black cherry. The Sem joint is unaffected by changes in equilibrium moisture content from 6 to 12 to 18 to 6 percent. Panels containing Sem joints have about the same stiffness as panels without Sem joints. When tested to failure in bending, panels with Sem joints were weaker than control panels. However, the panels had to bend much farther than nonstructural applications would dictate before failure occurred. When making the joint, some side pressure and end pressures of 60 to 240 psi are needed.

Introduction

The serpentine end-matched (Sem) joint (Fig. 1) has created considerable interest among furniture manufacturers because it allows them to end join short lengths of high-value hardwoods into aesthetically pleasing long lengths. Finger jointing is considered unacceptable for most exposed furniture parts because it produces a clearly visible straight line at right angles to the length of the strip. But the Sem joint is difficult, and often impossible, to detect because of its sine wave pattern and the precision with which it is machined (Hansen and Gatchell 1978).

Sem joints are made with a numerically controlled router that produces glue line thicknesses of about 0.001 inch (Gatchell et al. 1977). The proposed uses for the Sem joint are in nonstructural applications where two or more strips are edge glued together. Panels of widely varying grain and color that contain Sem joints have been found acceptable by manufacturers who have used them to build demonstration pieces of furniture.

Despite this acceptance, questions often are asked about the strength or performance of the Sem joint because it is essentially a curved butt joint. This limited study of strength and dimensional stability was conducted to provide potential users with answers to these questions. In Part I, we looked mainly at the performance of the joint under changes in equilibrium moisture content (EMC) and at the bending strength of panels containing Sem joints. In Part II, we evaluated the manufacturing variables of end and edge pressure on the strength of the Sem joints in tension.

Part I:
Dimensional Stability and Strength in Bending

The sine wave shape of a Sem joint is defined by its amplitude and period (Fig. 2). We used 2-1/2, 5 and 1-1/2, 5 Sem joints in this study. A 2-1/2, 5 Sem joint has an amplitude of 2-1/2 inches and a period of 5 inches. A 1-1/2, 5 Sem joint is flatter in appearance because the amplitude is decreased. Numerical control tapes for Sem joints of different amplitudes and periods are easy to generate with Coleman's (1977) SEMTAP program. All that is required for input is the amplitude and period of the sine wave and the radius of the router bit.

In making the joints, a cold-setting aliphatic resin adhesive, obtained commercially, was applied by brush to one of the joint surfaces. All joints were made by applying an unknown but heavy end pressure with screw-type pipe clamps. Side pressure at the outer edge of each joint was applied by tightening a C-clamp.

Effect of Changes in Moisture Content on Panel Surface Smoothness

When used in the construction of a panel for fine furniture, how will the Sem joint perform with changes in moisture content? Will the joint maintain its integrity when subjected to variations in EMC? To find out, we made two unfinished panels each of northern red oak, black walnut, and black cherry according to the design shown in Figure 3. The 2-1/2, 5 Sem joint was used. The panels were equilibrated at 80°F-30 percent relative humidity (RH); then at 80°F-65 percent RH; then at 80°F-80 percent RH; and again to 80°F-30 percent RH. This EMC cycle of 6 to 12 to 18 to 6 percent is far more severe than any cycles that could be expected in normal use.

The technique used for measuring panel surface smoothness was described by Peters and Mergen (1971). It is a precise technique that uses a stylus tracing head that was designed specifically for wood. The apparatus was sensitive enough so that the wood anatomy and raised or sunken joints would show clearly. Surface smoothness was measured for each moisture content.

The results of these tests were most pleasing. The Sem joints could not be identified on any panel at any moisture content. It made no difference whether the stylus went along or across the grain; whether the panels were flat or edge grained; or whether the panels were made from black walnut, black cherry, or northern red oak.

Strength in Bending of Panels With and Without Sem Joints

To evaluate bending strength, black cherry panels were made as shown in Figure 4. The 40-inch-long panels were made of strips of wood that had been selected for straightness of grain. The panels were surfaced to 0.7 inch in thickness and crosscut to two panels 20 inches long — one with a Sem joint and one without. Because the wood, the gluing procedures, and the processing were essentially the same for each half, differences in bending strength between each half of the 40-inch panel were attributed to the Sem joint. For destructive bending tests, we made four 40-inch panels. A panel contained either a 1-1/2, 5 or a 2-1/2, 5 Sem joint that was either centered or located at one edge. The panels were placed on supports spaced 18 inches apart and the load was applied at the peak of the Sem joint.

We also conducted nondestructive bending tests so that the Sem joint itself could be later tested in tension Using only centered joints (layup 1), we made two panels containing 1-1/2, 5 and two panels containing 2-1/2, 5 joints. Following the nondestructive tests of the modulus of elasticity (MOE), the Sem joints were carefully sawed from the panels and tested in tension.

Figure 1.—Sem joints are machined precisely with a numerical control router. When a router bit passes through a piece of wood on a curved path (A), the resulting pieces cannot be pushed together (B) because the path of one side of the bit is different from that of the opposite side. However, with a numerical control router, one side of a glue line can be machined on one piece of wood (vertical lines) and the other side on another piece (horizontal lines). When the waste is removed, the pieces fit together (C).

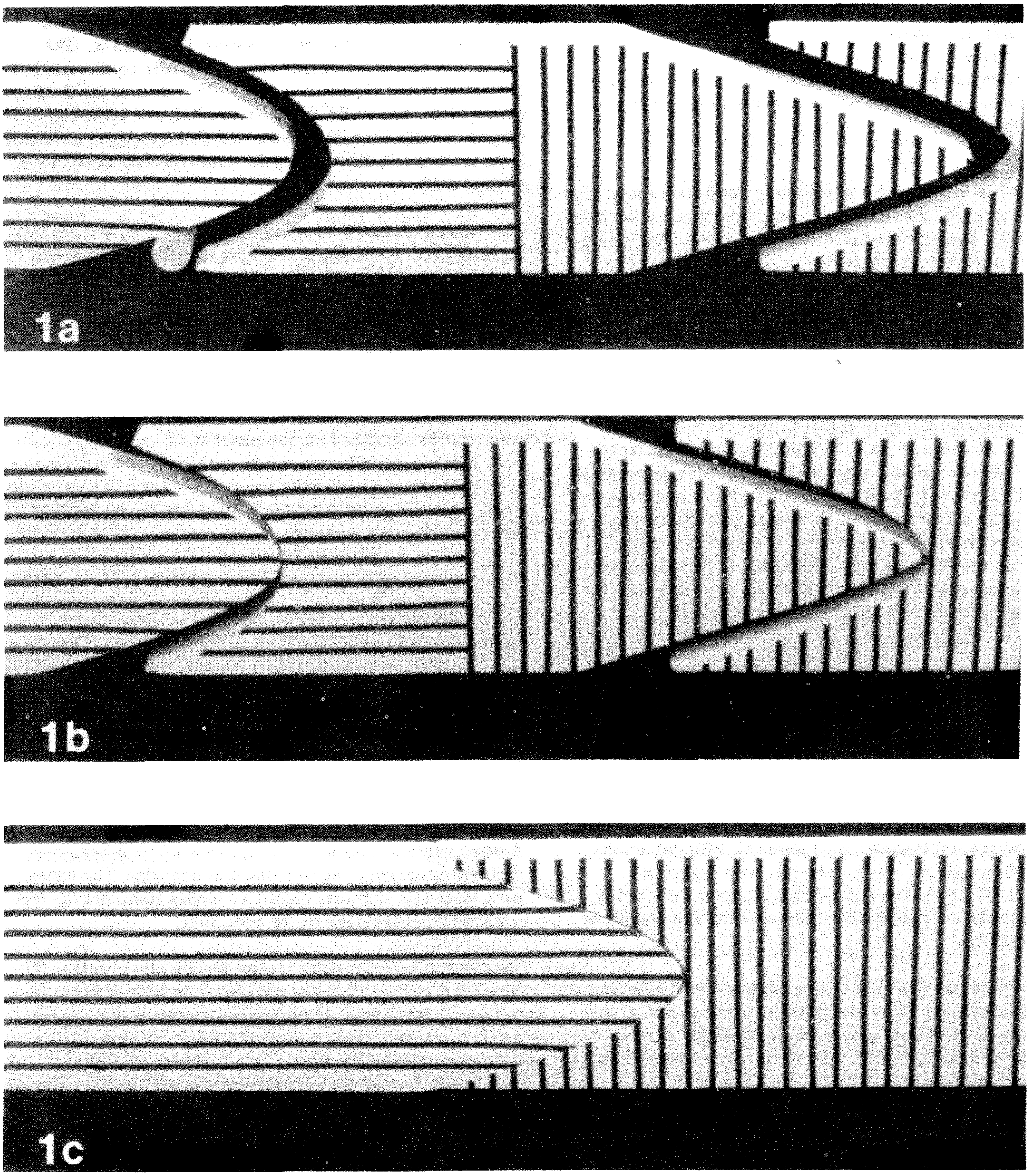


Figure 2.—The Sem joint resembles one-half of a full sine wave.

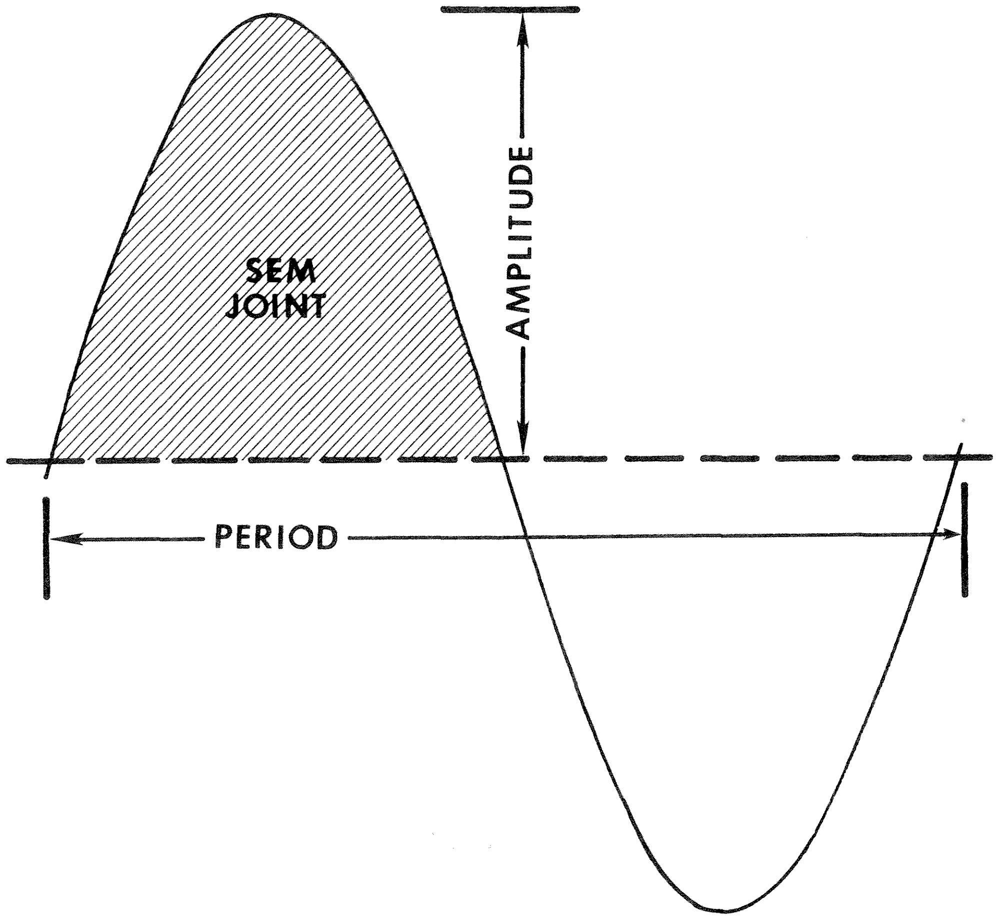


Figure 3.—Panel design for dimensional stability tests.

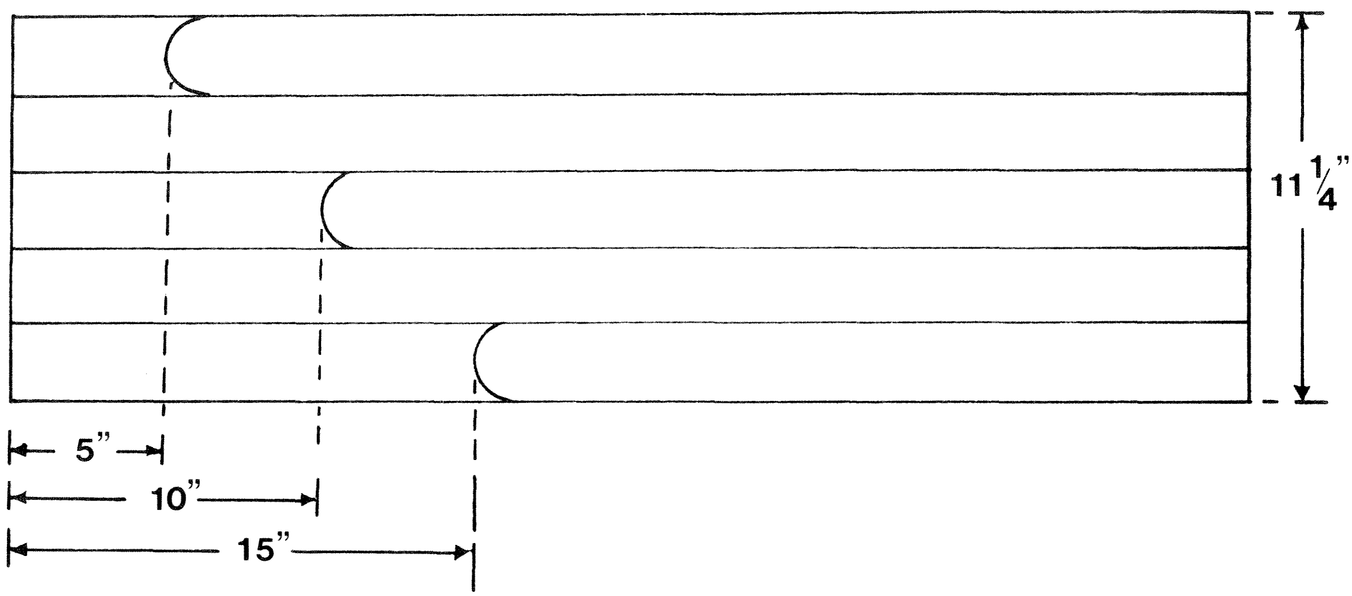
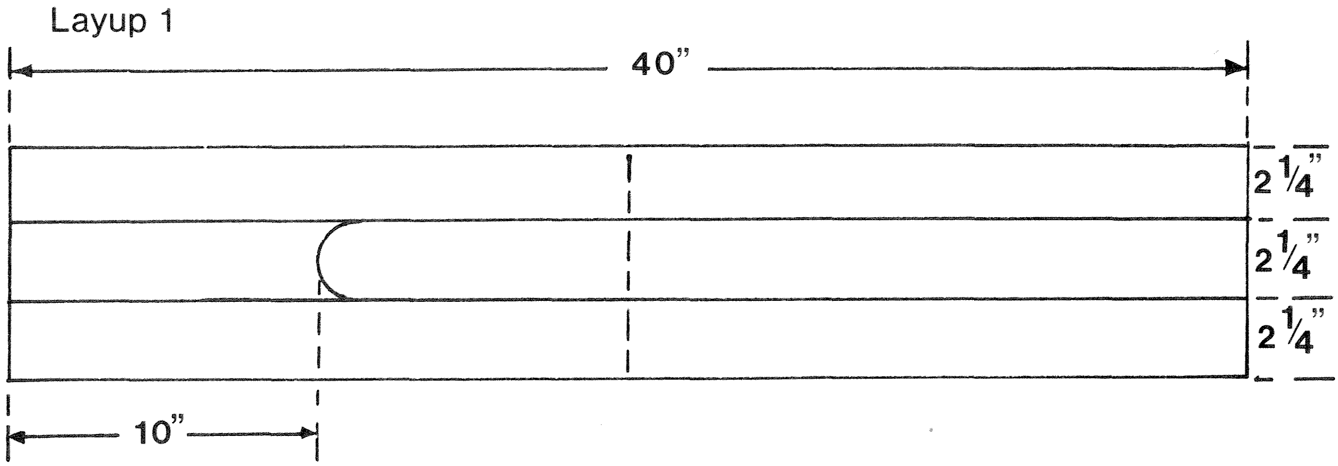


Figure 4.—Panel design for static bending tests.



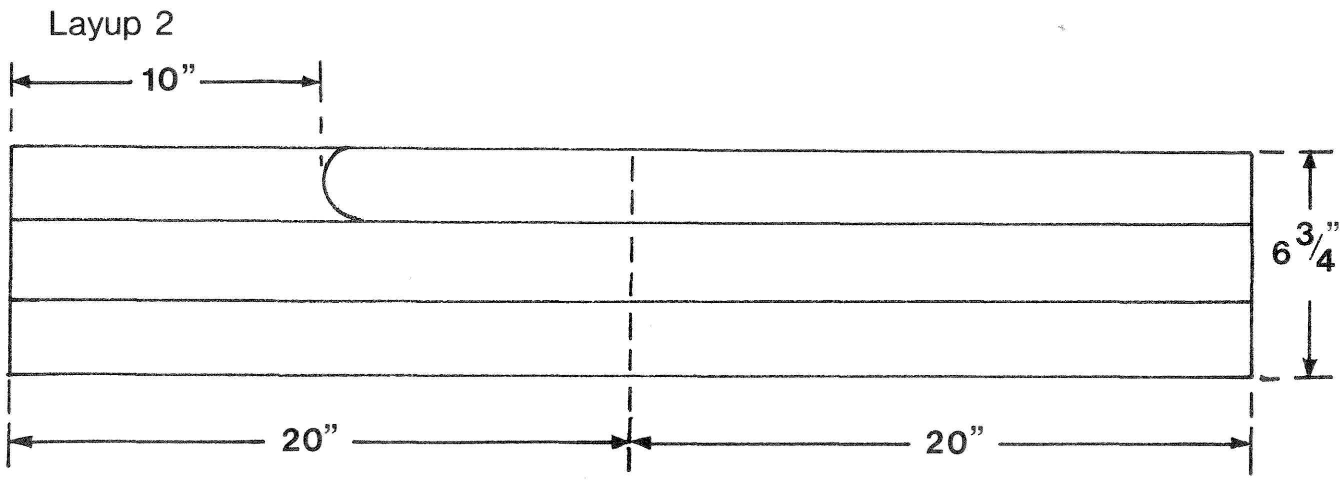


Table 1. Results of tests of panel failure in bending and of tensile strength of Sem joints

Test variable	Panels with Sem joints		Control panels		Tensile strength of Sem joints
	Maximum load	Modulus of elasticity (psi)	Maximum load	Modulus of elasticity (psi)	
	lb	*(thousands)*	*lb*	*(thousands)*	*psi*
Destructive test					
2-1/2, 5 (centered joint)	1,815	1,800	2,585	1,830	—
2-1/2, 5 (edge joint)	1,625	1,830	2,640	1,925	—
1-1/2, 5 (centered joint)	1,610	1,425	2,190	1,670	—
1-1/2, 5 (edge joint)	1,340	1,775	2,410	1,790	—
Nondestructive test					
2-1/2, 5 (centered joint)	—	1,580	—	1,475	1,827
2-1/2, 5 (centered joint)	—	1,460	—	1,525	2,224
1-1/2, 5 (centered joint)	—	1,580	—	1,630	1,505
1-1/2, 5 (centered joint)	—	1,615	—	1,615	1,619

The results of the nondestructive and destructive tests are given in Table 1. The most important factor in the application of nonstructural Sem panels is panel stiffness that is indicated by the MOE. Comparing the MOE's of panels containing Sem joints with the controls, we conclude that the Sem joints had no effect on stiffness. In six of the eight panels containing Sem joints, MOE values were slightly lower than in their controls, but these differences were not considered of practical significance.

In the destructive tests, the maximum load was affected both by the presence of Sem joints and the position of the Sem joints relative to the edge of the panels. In panels with Sem joints, two-thirds of the width was free of end joints. These panels were about two-thirds as strong as the controls (the range of values was 55 to 73 percent of controls).

Panels with joints in the center were about 15 percent stronger relative to the controls than panels containing joints in the outer strips. The difference in amplitude between the 1-1/2, 5 and the 2-1/2, 5 joint was not considered important. The four tests of joints in tension suggest that joint amplitude may be important to individual joint tensile strength. Even so, all four joints were surprisingly strong.

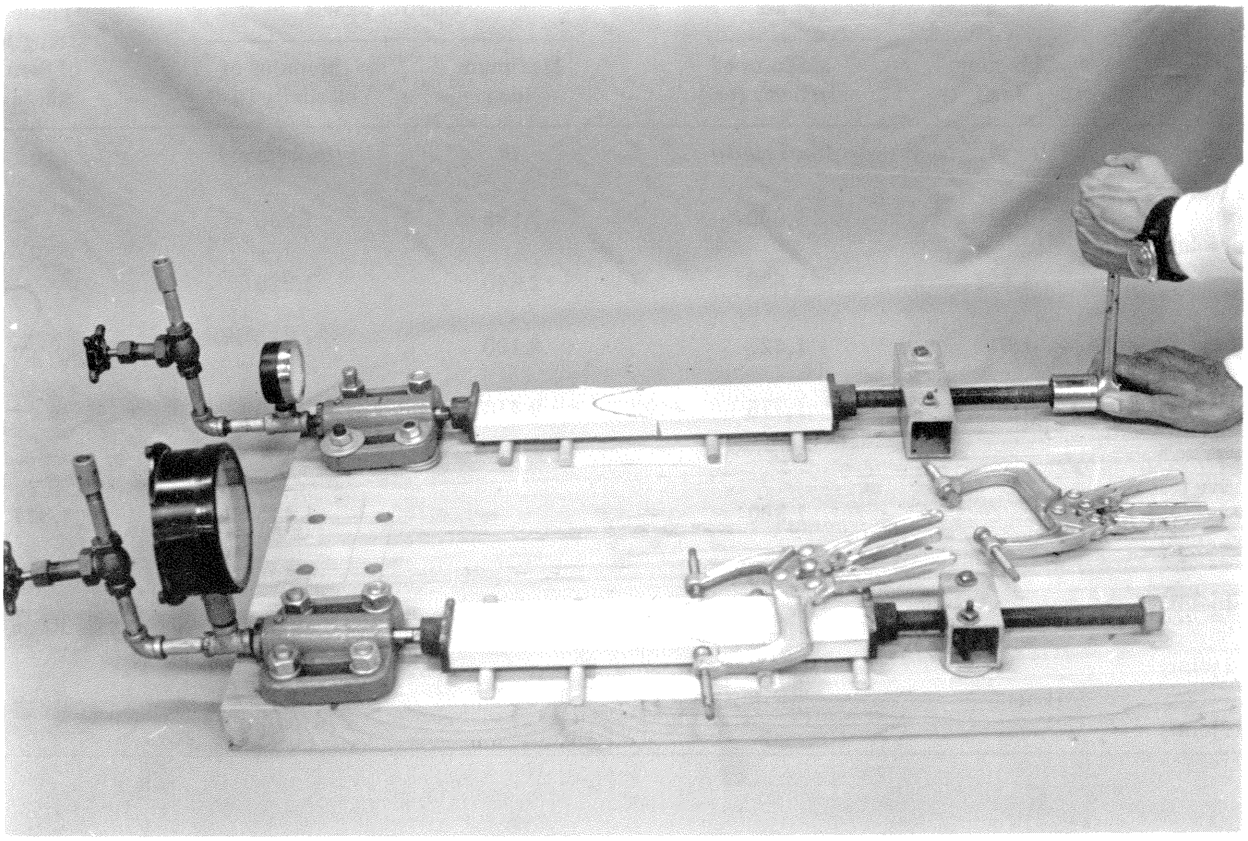
In discussions of panel bending strength, a most significant factor overrides the tabular values. The 0.7-inch-thick panels were placed on supports spaced 18 inches apart. A deflection of at least 0.6 inch was required over an 18-inch span before "catastrophic" failure took place. A load of at least two-thirds of a ton was needed to produce this deflection. We know of no furniture or other nonstructural applications where such a deflection or the support of such a load is required. Thus, discussions of maximum load are of limited value, at best.

Part II:
End and Side Gluing Pressures

The precision with which the Sem joint can be machined suggests that relatively small end pressures are needed for satisfactory bonding. But, how much is enough? Is side pressure necessary? Answers to such questions are needed before a commercial Sem gluing technique can be designed. To evaluate gluing procedures, we used the tension test. Results from these tests tell us, relatively, whether we are doing a good job of gluing.

In Part II there were significant changes in pressure application procedures and adhesives. A special device was built so

Figure 5.—This special gluing device allows the recording of end pressure used in the manufacture of Sem joints.



that end pressure could be recorded (Fig. 5) and two different commercial adhesives (A and B) were used. Each was defined as a modified polyvinyl acetate emulsion adhesive that is crosslinked (thermoset) by the addition of the appropriate catalyst. A filler was used with adhesive A. Some of the properties of the adhesives were:

Item	*Adhesive A*	*Adhesive B*
Solids (percent)	50 to 56	50 to 56
Adhesives pH	4.0 to 5.0	4.5 to 5.5
Adhesive and catalyst pH	2.5 to 3.5	2.5 to 3.5
Adhesive and catalyst viscosity (centipoises)	1,200 to 2,000	2,000 to 3,000

The shape of the concave side of the Sem joint presents a minor gluing problem. The interaction of the moisture in the adhesive and the feather edges of the concave side of the Sem joints can cause wide or open joints at the outer edges. This opening can be easily closed by hand pressure. Side pressures, applied by spring-releasing hand clamps, included none, restraint, and heavy. For restraint, the closed hand clamp was adjusted until it fit snugly above the concave side of the joint. The clamp was then released and applied again at the feather edges of the joint. Heavy side pressure was achieved by closing an adjustable pressure foot about 0.06 inch beyond the restraint side pressure opening.

In addition to using side pressure, we used a force-fitting joint in Part II. This was done by simply specifying a slightly larger period for the convex side of the joint and leaving the 2-1/2-inch amplitude the same for both sides. For these tests, the width of the base of the convex side was 2.505 inches; the concave side was 2.500 inches.

Each joint was placed in the end-pressure device about 1 minute after glue was applied by brush to each face. The gage pressure plate moved as pressure was applied; thus, the sample was supported on each side of the joint by two dowels so that it was free to move. After end pressures of 60, 120, 240, or 400 pounds per square inch (psi) were applied, the side pressure was introduced. The assembled joint was left in the clamps for 30 minutes. Tests in tension were conducted several days later.

At the very peak of the joint, end grain is glued to end grain; that is, the glue line is at an angle of 90° to the grain of the wood. From the peak and through a distance of about 1/2 inch along the glue line, the glue line angle changes rapidly to about 30°. Then, the angle of the joint face changes slowly to about 20° from parallel to the grain at the outer edge. While these are hardly optimum grain angles for gluing, the Sem joints perform well in tension tests.

The samples failed in tension at the glue line. Often, there was some wood failure in the weaker wood elements. In oak, for example, wood failure often occurred along all of the glue line except at the peak of the joint. Failure was mainly in the wood rays and springwood vessel areas. Careful observation was needed to note this wood failure, however, and most joint failures appeared fairly clean to the naked eye.

The Sem joints were surprisingly strong. Samples of the force-fitting 2-1/2, 5 Sem joints were ripped into 1/4-inch strips and tested in tension by the adhesive manufacturer. For the 1/2 inch of glue line at the peak, 27 cherry samples yielded an average strength in tension of 3,170 psi and 15 hard maple samples had an average strength of 3,480 psi.

Adhesive A

Adhesive A, with 5 percent catalyst and 5 percent filler was used to evaluate the effects of end pressure on matched samples of cherry and oak. All samples for each species were from one board. "Restraint" side pressure was used on all joints at the 5 percent filler level. For both cherry and oak, strength in tension decreased as end pressure increased from 60 to 240 psi (Table 2).

The effect of side pressure on oak joints was evaluated at an end pressure of 120 psi with adhesive A, with 5 percent catalyst and 10 percent filler (Table 2). There was not a great difference in the tension values. The use of restraint side pressure produced values about 150 psi higher than no or heavy side pressure. This difference was not considered important.

Adhesive B

Adhesive B, with 5 percent catalyst and no filler, had a higher initial viscosity than adhesive A. It was easier to apply. Within 3 hours, the viscosity had increased to that of a very thick latex paint. The adhesive could be easily spread over an 8-hour period.

The results obtained from the end pressure tests with adhesive B (Table 3) did not show trends as distinct as those with adhesive A. For cherry at all side pressures and for oak under restraint side pressure, an end pressure of 120 psi resulted in slightly higher values than 60 psi, though the differences were not considered important. With restraint side pressure, 240 psi had about the same effect as 120 psi in cherry, oak, and maple.

Table 2.—Effect of end and side pressure on tensile strength of Sem joints glued with adhesive A (in psi)[a]

Species	Percent filler	Side pressure	End pressure (psi)		
			60	120	240
Cherry	5	Restraint	2,280	1,940	1,540
Oak	5	Restraint	2,840	2,590	2,380
Oak	10	None	—	2,530	—
Oak	10	Restraint	—	2,710	—
Oak	10	Heavy	—	2,550	—

[a] All values are an average from three tension tests.

Table 3.—Effect of end and side pressure on tensile strength of Sem joints glued with adhesive B (in psi)[a]

Species	Side pressure	End pressure (psi)			
		60	120	240	400
Cherry	None	2,380	2,950	—	510
Cherry	Restraint	3,035	3,250	3,180	—
Cherry	Heavy	1,650	1,800	—	3,730
Oak	Restraint	2,340	2,780	2,760	—
Maple	Restraint	—	3,380	3,340	3,360

[a] All values are an average from at least three tension tests.

An end pressure of 400 psi produced highly variable results in black cherry joints. We believe that adhesive viscosity and the shape of the joint contributed to this variability. When adhesive B was freshly mixed and the viscosity was low, the resulting joints had a starved appearance. While the joints appeared excellent to the naked eye, under magnified viewing (to 80X), problems were encountered when no side pressure was used. These joints were open at the outer edges and along the sides. We visualize that the joints were seated properly with enough glue at some end pressure less than 400 psi. As end pressure continued to be applied, there was excessive squeeze out and stress near the peak caused the outer edges to open out. Squeeze out was not excessive when the viscosity increased. The 400 psi joints bonded with heavy side pressure were made when the adhesive viscosity was similar to thick latex paint. The heavy side pressure closed the open outer edges and high strength resulted.

In black cherry, restraint side pressure produced higher strength values at end pressures of 60 and 120 psi than did no or heavy side pressure.

Sugar maple and black cherry occasionally suffered slightly from torn or chipped grain on the infeed side of the concave side of the joint. While clearly noticeable under the microscope, this minor problem did not prevent high tension values for these species. Router bits with a different rake angle might not tear the grain at all. Torn grain was not observed in oak or walnut.

Conclusions

The performance of Serpentine end-matched joints and of panels with Sem joints was excellent. Manufacturers need not be concerned that the Sem joint will create problems in panels as a result of changes in moisture content before or after a finish is applied. The stiffness of panels containing a Sem joint is about the same as panels without Sem joints. While the maximum load, as determined by static bending tests, is reduced by Sem joints, it is doubtful that these factors are important in nonstructural applications. Our 0.7-inch-thick panels had to deflect at least 0.6 inch over an 18-inch span before "catastrophic" failure took place.

The precise manner in which the Sem joint is machined allows the use of relatively low assembly end and edge pressures. End pressures should be great enough to bring the two sides of the joint together but not so great as to cause excessive squeeze out or to force open the concave side of the joint. When the two sides of the joint are free to move, end pressures between 60 and 240 psi are effective. Some side pressure is desirable to prevent the feather edges from opening, but only restraint side pressure is needed. Under these conditions, a strength in tension of more than 2,000 psi can be achieved.

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Keywords: Panels; end gluing; edge gluing; numerical control routers