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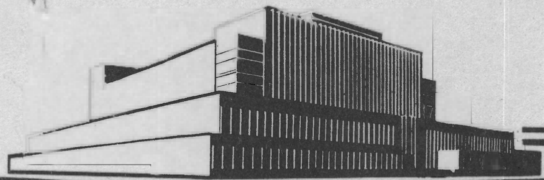

FOREST PRODUCTS LABORATORY
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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
In Cooperation with the University of Wisconsin

TEST FOR QUALITY OF GLUE BONDS IN END-JOINTED LUMBER[1]

By

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Synopsis

Development of a tension test suitable for quality control on finger joints and other end joints in wood is described. The specimen used is rectangular and can be prepared rapidly with a planer-type table saw. The approximate size of the specimen is 3/32 by 3/4 inch in cross section by 10 inches in length.

Because the specimen is simply prepared and can be tested quickly on a universal testing machine, it is also well suited as a screening tool in research and development on end joints in wood.

Introduction

Splicing of wood endwise by mechanical means has probably been practiced as long as recorded history. Glued end joints, on the other hand, have come into extensive use only within the past few decades. The glued end joints can be divided roughly into two types, scarf joints and finger joints. The scarf joints have been used for end-jointing structural material, whereas finger jointing has been confined mainly to nonstructural uses.

Within recent years, however, there has been considerable interest in developing finger joints suitable for structural purposes, and at least one country

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[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

(West Germany) has published specifications (DIN 68140, June 1960) that give specific designs and manufacturing procedures for finger joints to be used in members subjected to high mechanical stress as well as for less severe usages.

The reason for the large increase in finger jointing of nonstructural material within the past few years is that it enables marketing of standard clear sizes, which are more salable than mixed sizes of lower grades, and also reduces labor cost at the place of use. The interest in finger jointing for structural purposes is prompted by the greater saving in material that can be realized by this method as compared to scarf jointing. It is also believed that greater uniformity in joint quality can be maintained by finger jointing than by scarf jointing, although it is not expected that finger joints will be as strong as scarf joints of the same slope unless practical means can be developed for making finger joints with extremely sharp points. Finger joints with sharp points have been reported to approach the full strength of wood, particularly with lower density species.[3]

A program of research on finger jointing has been underway for some time at the Forest Products Laboratory. It was soon realized, however, that the methods available for evaluating end joints were not too well suited either for development work or for quality control.

A necked-down tension specimen (fig. 1) has been used to determine the ultimate tensile strength of end joints. For the purpose of quick evaluation of various experimental joint designs or for quality control of production, however, this type of specimen is too costly and time consuming to produce, and a rectangular tension specimen was adopted.

Description of Tension Specimens

A rectangular tension specimen cut with a planer-type table saw was believed to be adequate for approximate evaluations of finger joints, and possibly also other end joints, to use in place of the necked-down specimen used in earlier research. The necked-down specimen requires an appreciable amount of material and, as indicated earlier, the shaping of the specimens to the desired contour on all four sides is time consuming. As a first trial, thin rectangular slats with finger joints at the center were tested in a plywood-shear machine. For weaker joints this proved adequate, but for strong joints and unjointed

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[3] Pavlov, U. P. Joining Wood Longitudinally with Toothed Tenons. Commonwealth Scientific and Industrial Research Organization Translation No. 2705, Commonwealth of Australia. (Translated from Wood Processing and Wood Chemical Industry, 3(10): 5-8, 1954. U.S.S.R.)

controls, too much crushing and breaking at the grips developed. Self-tightening wedge or Templin-type grips in a Universal testing machine were used next, and with these, the results looked much more promising. The Templin grips used had gripping areas 1-1/4 by 1-1/4 inches.

A rectangular specimen that gave values reasonably close to those of a necked-down specimen (modified ASTM necked-down tension specimen 3/4 by 1/4 inch at the thin section) was approximately 3/32 by 3/4 by 5 inches.

The necked-down specimens were 26 inches long, and the minimum section at the center was 3/4 inch wide, 1/4 inch thick, and 6 inches long (extending 3 inches either way from the midpoint of the joint). At either end, the maximum section was 2-5/16 inches wide and 3/4 inch thick over a 5-inch length. The maximum and minimum sections were connected by a transition section with a radius of 17-1/2 inches. (The general shape of the specimens is shown in figure 1.)

The length of the fingers of the finger joint used was about 1 inch, the tips about 0.008 inch thick, and the pitch 0.2 inch. This was the joint design used in all of the tests discussed in this report, unless otherwise stated. The joints were cut by mounting the cutter head on the spindle of a vertical shaper. A phenol resorcinol glue, cured with electro-thermal heating pads, was used for bonding the joints. The wood, in general, was at 12 percent moisture content when glued and also when the specimens were tested.

Tips as thin as 0.008 inch would probably not be suitable for production finger jointing at the current state of development in cutters, but the joint design used demonstrated that high strength can be obtained with a finger joint only about an inch long when rather sharp tips are used.

In the first series of tests using side-matched rectangular and necked-down specimens of Douglas-fir, the samples were finger jointed in sizes about 7/8 by 3-1/2 by 30 inches; from each of these, two necked-down specimens (in one case one) and five to six of the smaller rectangular specimens were prepared. The average of 11 necked-down finger-jointed specimens was 15,494 pounds per square inch and that of 32 rectangular ones, 15,989 pounds per square inch (table 1).

In another series, 40 necked-down and 120 rectangular finger-jointed specimens were prepared from side- and end-matched Douglas-fir material. All specimens in each group were side matched, and the five groups were end matched consecutively (from a plank 3-1/4 by 7 inches by 14 feet). Results of tension tests of these specimens are summarized in table 2.

Although, in general, the necked-down specimens gave slightly higher results than the small, rectangular ones (table 2), variance analysis of the data showed no significant difference between the means of the two sets of data.

For a quick evaluation of joint quality and for screening purposes in research, the test method appeared very promising.

Figure 1 illustrates the two types of specimens used and indicates to some extent the types of breaks that occured. Both types of specimens were 3/4 inch in width at the joint area, and the corresponding specimens for each test had the same number of wedge-shaped fingers. The rectangular ones can be cut very rapidly with a planer-type table saw (fig. 2). The other type is necked-down on all four sides and is prepared on a shaper using suitable jigs.

Strength ratios were also calculated for the five groups of specimens and are shown in table 2. With the weakest group, the strength ratio was very high, but as the strength increased the spread between jointed specimens and controls showed an appreciable increase.

This indicated that, with the particular joint design used, the full strength of Douglas-fir can be approached in lower density material and that the difference between joint strength and controls increases with density.

Since breakage near the grips occurred at times in the rectangular specimens, resin coatings were sometimes used as a means to reinforce the ends. The following section discusses the effect of one type of resin coating.

Effect of Resin Coating on Rectangular Tension Specimens

Dipping the ends of the specimens, slightly beyond the area covered by the grips, in warm polyvinyl resin-emulsion glue and permitting the glue to dry for 4 hours apparently increased the strength slightly. It appeared possible that the plastic coating slightly reinforced the ends of the specimens, resulting in less crushing under the grips. To determine if this apparent increase in strength was significant or not, 15 rectangular specimens were taken from each of four southern pine boards and from each of two Douglas-fir boards (these specimens were solid and not jointed). The boards were all flat grained, and the specimens from each board were side matched. The faces of the specimens were edge grained, and they were numbered consecutively from one edge of the board to the other. The odd-numbered ones were coated on the ends with polyvinyl-emulsion glue before testing, and the remainder were tested without coating. The results are summarized in table 3.

Although the average strength for the coated specimens was higher than that of the uncoated for every board, the difference was statistically significant (on the 5 percent level) only for one board (of southern pine). This was the board that developed the highest tensile strength of those tested. When the results from all the pine specimens were analyzed as a group, however, the difference between coated and uncoated specimens was highly significant (at the 1 percent level). With a larger number of specimens, the difference possibly would have been significant with the Douglas-fir also, although it appears reasonable that with lower strength material (the particular Douglas-fir used was lower in density than the pine) the effect of crushing under the grips becomes less significant.

Although dipping the specimens in polyvinyl glue appeared to have some beneficial effect in reducing crushing at the grips and increasing strength, it required additional time for the application and the subsequent drying. Hence, grips with larger gripping areas (1 by 3 inches) were tried and with these, crushing appeared not to be a problem. Because 3 inches at each end of the specimen were covered by the grips, longer specimens were required than those used with the smaller grips. Since the length of the specimens could easily be varied, and the width, when testing finger joints, was somewhat dependent upon the joint design, it was decided to investigate the effect of width and length within certain limits.

Effect of Length and Width of Specimens

The greater the length-width ratio in a tension specimen, the less important is any misalinement of the specimen in the grips. In order to determine the effect of length and width of specimens of the type used, tests were made on specimens 8, 10, and 12 inches in length and 1/2, 3/4, and 1 inch in width. All specimens were about 3/32 inch thick. Sitka spruce was used because of its uniform grain texture, and an equal number of samples was taken from three different boards. Unjointed specimens were used because effect of width and length would be expected to be about the same as for jointed ones at the same strength level, and also because any effect of dimensions would more likely be detected in strong unjointed specimens than in weaker jointed ones.

From each board, six samples were taken of each of the three lengths. For each length, two specimens were about 1 inch in width, two about 3/4 inch, and two about 1/2 inch, totaling 18 specimens from each board and 54 for the three boards.

The average tensile strength of the specimens was 15, 858 pounds per square inch for the 12-inch length, 15, 794 for the 10-inch length, and 16, 193 for the 8-inch length. When averaged by width, the strength values were 15, 385 pounds per square inch for the 1-inch wide specimen, 16060 for the 3/4-inch, and 16, 401 for 1/2-inch specimens.

An analysis of variance for effect of lengths and widths of specimens showed no significant difference (at the 5 percent level), but the actual difference between the 1-inch and 1/2-inch specimens was about 9 percent and came very close to being significant on the 5 percent probability level. An analysis of results by length-width ratio did not show a significant difference on the 5 percent level, but again the difference did come close to being significant at this level.

The length, of course, can be easily varied in finger-jointed specimens (within the practical limit of the test machine), but setting the width at some specific value for different designs of finger joints is more problematic. Figure 3 shows a specimen in the grips that has four finger tips (in the specimen) at each end of the joint. The outer finger comes to a feather edge at about the middle of the joint on each edge of the specimen. The practice in testing finger joints at the Forest Products Laboratory has been to include, whenever feasible, a multiple of full fingers and an equal number of tips at each end of the joint, with the two outer fingers coming to a feather edge at the midpoint of the joint. In this manner, the different joint designs appear to be given an equal opportunity to develop their maximum strength. If, on the other hand, a constant width of specimen had been chosen for testing, one joint might be tested with a tip exposed on the edge, which would be detrimental to maximum strength development, and another might be tested with a greater number of tips at one end of the joint than at the other, which could be an unfair advantage over those tested with an equal number of tips at each end of the joint. Consequently, the width of the test specimens, within certain limits, is governed by the pitch of the fingers.

The specimen shown in figure 3 has four tips at each end of the joint, whereas the one shown in figure 4 (where specimen is just being inserted into machine) has only two tips at each end of the joints. The reason for this is the larger pitch of the joint in figure 4.

Evaluation of Joint Durability

The boil-cycle test[4] is often used to evaluate joint quality of plywood tension-shear specimens.[5] Since the rectangular tension specimens proposed for finger joints and other end joints are not a great deal different in size from the plywood shear specimens, the boil-cycle test was thought to be applicable to measure durability of finger joints and other end joints.

In quality control, time is usually an important factor and, inasmuch as the boil test requires a 28-hour exposure period (boil-dry-boil) before the specimens are tested, a shorter cycle was sought. Steaming has been used occasionally at the Forest Products Laboratory and elsewhere as a means of accelerating glue-joint deterioration and has in general been found to be more damaging than boiling, particularly to certain nondurable glues.

The "plywood boil-cycle test," as it is often called, consists of 4 hours of boiling followed by 20 hours of drying at 145° F.; plus an additional 4 hours of boiling, followed by cooling; and then testing the specimens wet. A procedure consisting of steaming of the specimens at 212° F. for 30 minutes followed by 30 minutes of cold-water soaking at 150 pounds per square inch pressure and then testing was found to give results reasonably close to that of the boil test, although the exposure time was reduced from 28 hours to 1 hour. The results of 25 finger-jointed Douglas-fir specimens (glued with a phenol-resorcinol adhesive and similar in design to those shown in figure 1) averaged 9, 255 pounds per square inch after the steam-soak test (1-hour exposure) and 9, 538 on similar matched specimens after the boil test (28-hour exposure). The strength of the dry controls was 12, 752 pounds per square inch. The wood-failure values were 63 percent for the steam-soak test, 67 percent for the boil test, and 52 percent for the dry controls.

A group of 35 commercially made Douglas-fir finger-jointed specimens were glued with a combination of equal parts by weight of a urea resin and a melamine resin glue. (The design of the joint was approximately 0. 1-inch-thick tips, 11/32-inch pitch, and 1 inch in length.) These specimens gave 1, 984 pounds per square inch and 43 percent wood failures after the steam-soak test and 1, 808 pounds per square inch with 40 percent wood failure after the boil-cycle test; the dry controls (specimens from the same group tested at 12 percent moisture content) developed 3, 492 pounds per square inch with 79 percent wood failure.

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[4] U. S. Department of Commerce. Commercial Standard for Douglas-fir Plywood, CS 45-60.

[5] American Society for Testing and Materials. Testing Veneer, Plywood, and Other Glued Veneer Constructions. ASTM D805-52.

A set of ponderosa pine joints (fig. 1 design and glued with a phenol-resorcinol adhesive) averaged 9,665 pounds per square inch and 33 percent wood failure when tested dry (12 percent moisture content), 6,019 pounds per square inch with 53 percent wood failure after the steaming and soaking, and 6,074 pounds per square inch with 54 percent wood failure after the boil test. Fifteen specimens were used for each test.

A group of commercially glued southern pine finger joints bonded with urea-resin adhesive all failed with zero load and zero wood failure after the 1-hour steam-soak exposure. Results on dry controls (12 percent moisture content) averaged 4,368 pounds per square inch with 60 percent wood failure. A set of these specimens was also subjected to a vacuum-pressure soaking-drying test[6] after which the results averaged 1,850 pounds per square inch with 33 percent wood failure. It appears, therefore, that the 1-hour soak-steam test is a quick method of detecting a heat-sensitive adhesive, such as a urea-resin. The accuracy of the test in predicting long-term durability of finger joints would have to be determined by correlation with long-term weather exposures.

Adaptability to Scarf Joints

The test method appears to be as equally well adapted to scarf joints as to finger joints. When the scarf joints are cut with a rather low slope, such as 1 in 12, it is most practical to cut the tension specimens discussed in this report in such a manner that the 1 in 12 slope is exposed on the edge (3/32-inch dimension) of the specimens. If the distance between the grips is sufficient, they probably also could be cut with the slope of the scarf exposed on the wide face of the specimens, particularly for nominal 1-inch material. With 3-inch grips, the specimens would have to be at least 16 inches long when cut from a 3/4-inch board (6 inches covered by grips, plus joint of 9 inches, plus 1/2-inch clearance between grips and joint at each end).

Figure 5 illustrates how specimens can be cut from a scarf joint and two types of finger joints.

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[6] Five minutes vacuum (20 to 25 inches of mercury at sea level), 30 minutes under water at 150 pounds per square inch, dry 4 hours at 150° F., and test (Modified ASTM D1101-58).

Conclusions

The data presented indicate that testing of finger joints and other end joints by means of rectangular tension specimens about 3/32 inch thick, 1/2 to about 1 inch wide, and about 8 to 12 inches in length is suitable for quality control, and that the method is also a convenient screening tool in research.

The test method also appears adaptable to accelerated durability evaluation.

Table 1.--Comparison of results of tension tests on necked-down finger-joint specimens (cross section at joint 1/4 by 3/4 inch) and on rectangular finger-joint specimens 3/32 by 3/4 by 5 inches. All samples taken from one Douglas-fir board.

Rectangular specimens		Necked-down specimens	
Specimen[1] No.	Tensile strength	Specimen[2] No.	Tensile strength
	P.s.i.		P.s.i.
A3-1-1	16,000	B3-1-1	12,770
A3-1-2	18,777		
A3-1-3	17,781		
Average	17,519		
A3-2-1	18,065	B3-2-1	13,110
A3-2-2	14,722	B3-2-2	14,980
A3-2-3	14,945		
A3-2-4	14,797		
A3-2-5	12,300		
A3-2-6	15,070		
Average	14,983		14,045
A4-1-1	14,870	B4-1-1	15,980
A4-1-2	16,500	B4-1-2	15,820
A4-1-3	15,730		
A4-1-4	17,150		
A4-1-5	15,925		
A4-1-6	15,140		
Average	15,886		15,900
A4-2-1	17,150	B4-2-1	16,520
A4-2-2	17,845	B4-2-2	15,670
A4-2-3	18,575		
A4-2-4	18,065		
A5-2-5	17,900		
A4-2-6	14,722		
Average	17,376		16,095
A5-1-1	15,855	B5-1-1	15,680
A5-1-2	15,585	B5-1-2	15,910
A5-1-3	16,080		
A5-1-4	13,300		
A5-1-5	16,728		
A5-1-6	12,595		
Average	15,024		15,795
A5-2-1	14,010	B5-2-1	16,370
A5-2-2	16,430	B5-2-2	17,620
A5-2-3	14,945		
A5-2-4	17,350		
A5-2-5	16,728		
Average	15,893		16,995
Average of 32 tests	15,989	Average of 11 tests	15,494

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[1] The ends of these specimens were dipped in warm polyvinyl-emulsion glue which was allowed to dry before they were tested. This appeared to result in less crushing or splitting under the jaws. A wedge-type grip was used in testing.

[2] The samples were finger jointed in sizes about 7/8 by 3-1/2 by 30 inches. From each of these samples, two necked-down specimens (in one case 1) and 3 to 6 of the smaller, rectangular specimens were prepared. Average specific gravity of the material used was 0.48 (based on weight and volume of ovendry wood).

Table 2.--Comparison of results of tension tests on finger joints in Douglas-fir tested by two different methods.

Group No.[1]	Rectangular specimens					Necked-down specimens				
	Controls		Finger joints		Strength ratio	Controls		Finger joints		Strength ratio
	Number of specimens	Tensile strength	Number of specimens	Tensile strength		Number of specimens	Tensile strength	Number of specimens	Tensile strength	
		P.s.i.		P.s.i.			P.s.i.		P.s.i.	
1	12	11,575	24	11,710	101	4	12,173	8	11,638	96
2	12	11,798	24	10,018	85	4	12,950	8	10,833	84
3	12	14,606	24	11,586	79	4	13,925	8	12,350	89
4	12	12,822	24	12,474	97	4	13,430	8	11,995	89
5	12	15,425	24	13,015	84	4	17,025	8	13,325	78
Average:		13,245		11,760	89		13,900		12,028	87

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[1] All specimens in these tests came from one Douglas-fir plank, 3-1/4 by 7 inches by 14 feet. Groups 1 to 5 consecutively were end matched in that order. All specimens in one group were side matched. The average density for the entire plank was 0.51, with variation of 0.47 to 0.56 from one end (of the plank) to the other (based on weight and volume of ovendry wood).

Table 3.--Comparison of coated[1] and uncoated specimens[2] tested in tension.

Species	Coated specimens	Uncoated specimens	Significance of difference
	P.s.i.	P.s.i.	
Southern pine	17,346	16,049	N.S.[3]
Do.	20,794	18,607	Significant at 5 percent level
Do.	18,796	17,567	N.S.
Do.	19,283	17,969	N.S.
Average	19,055	17,548	Significant at 1 percent level
Douglas-fir	10,044	9,523	N.S.
Do.	14,281	13,178	N.S.
Average	12,163	11,351	N.S.

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[1] Area under grips coated with warm polyvinyl-emulsion glue. Each value shown is the average of 15 tests.

[2] The specimens were 3/32 by 3/4 inch in cross section and 5 inches in length.

[3] N.S. = Not significant at 5 percent level.

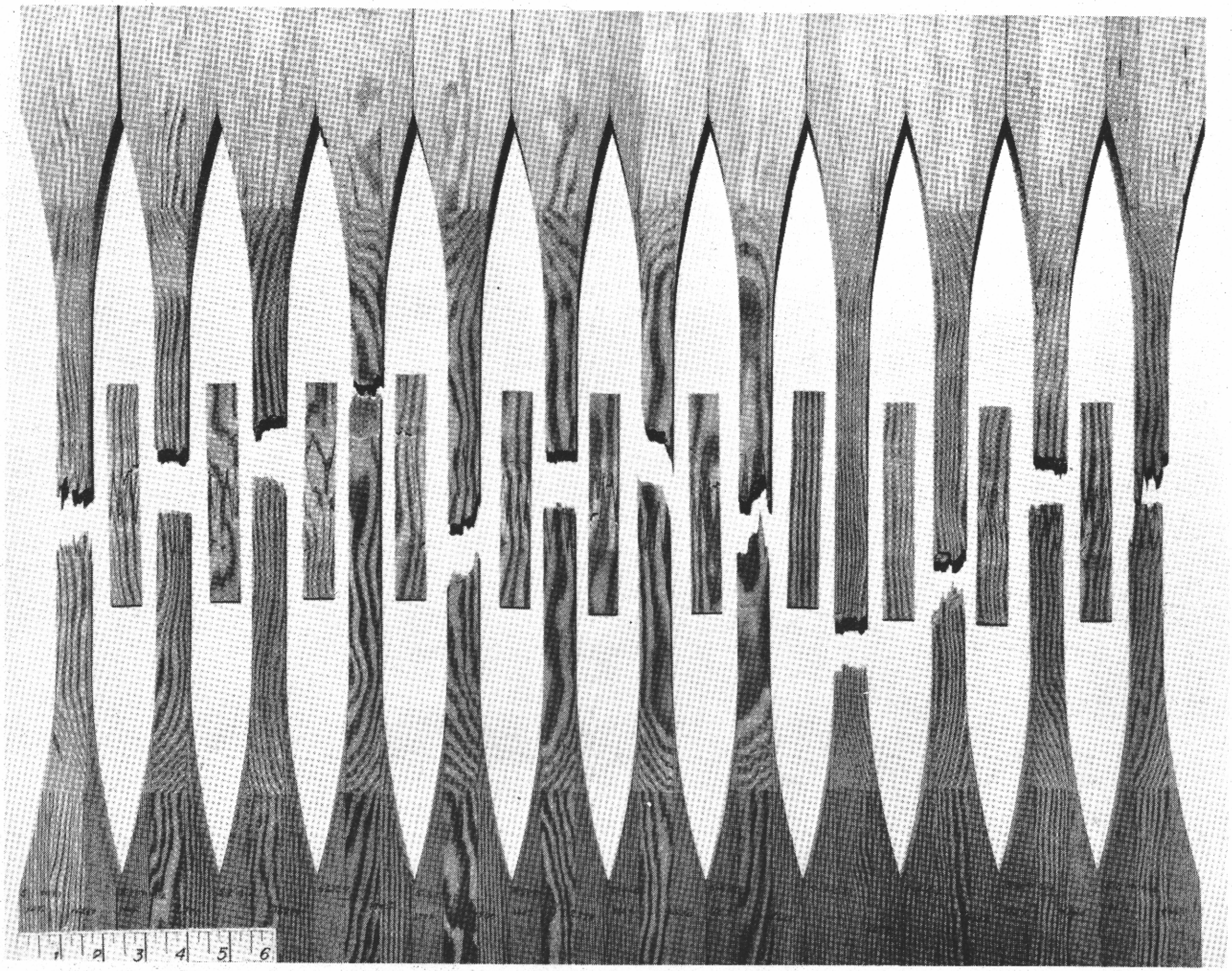

Figure 1. --Rectangular and necked-down finger-joint specimens and controls broken in tension.

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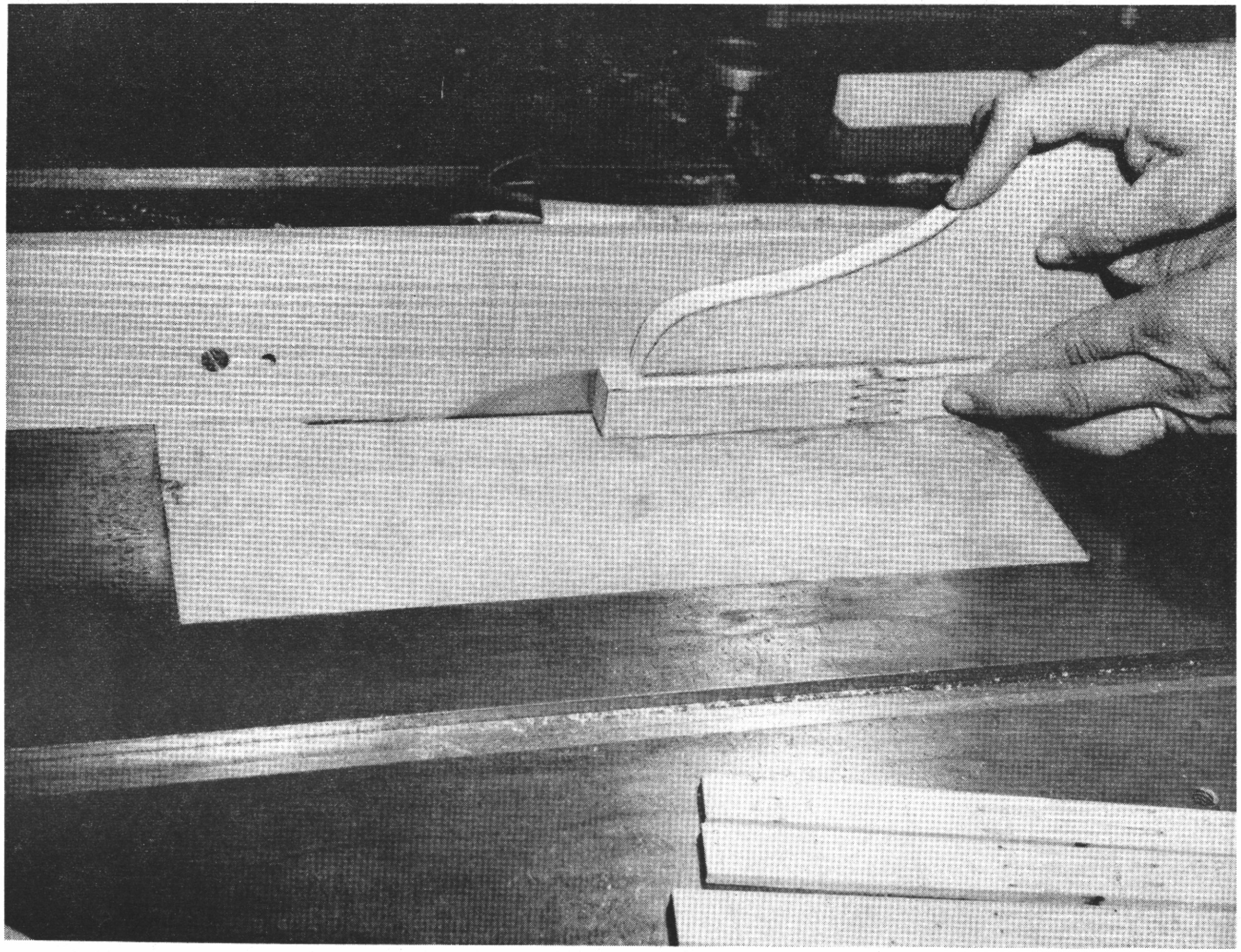

Figure 2. --Cutting rectangular tension specimens on a planer-type table saw.

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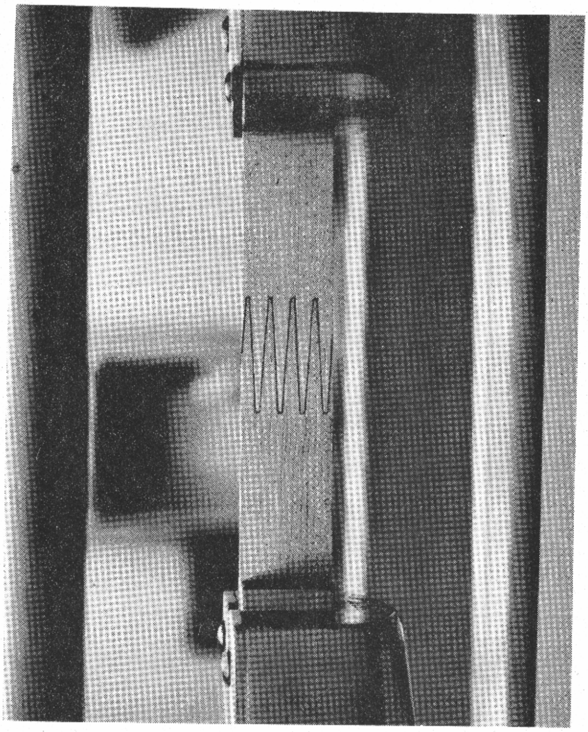

Figure 3. --Rectangular finger-jointed tension specimen in test grips ready for testing.

(ZM 101 231)

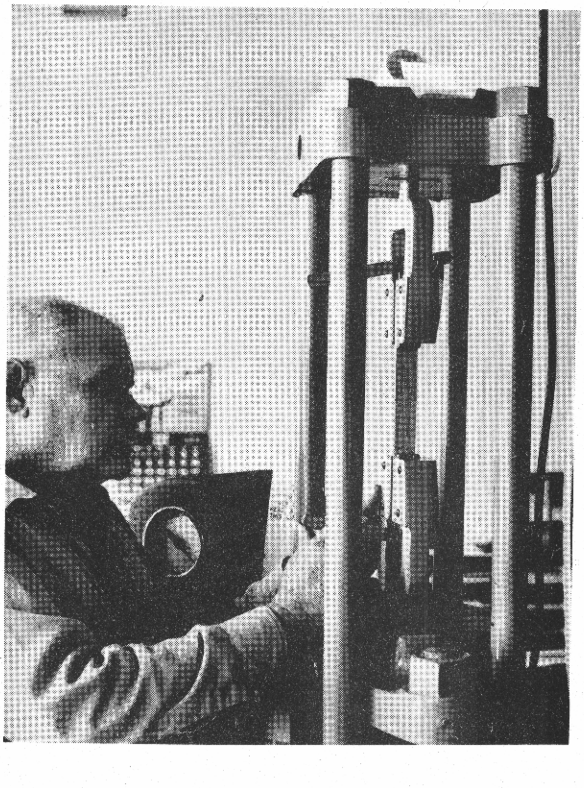

Figure 4. --Rectangular finger-jointed specimen being placed in wedge grips for testing.

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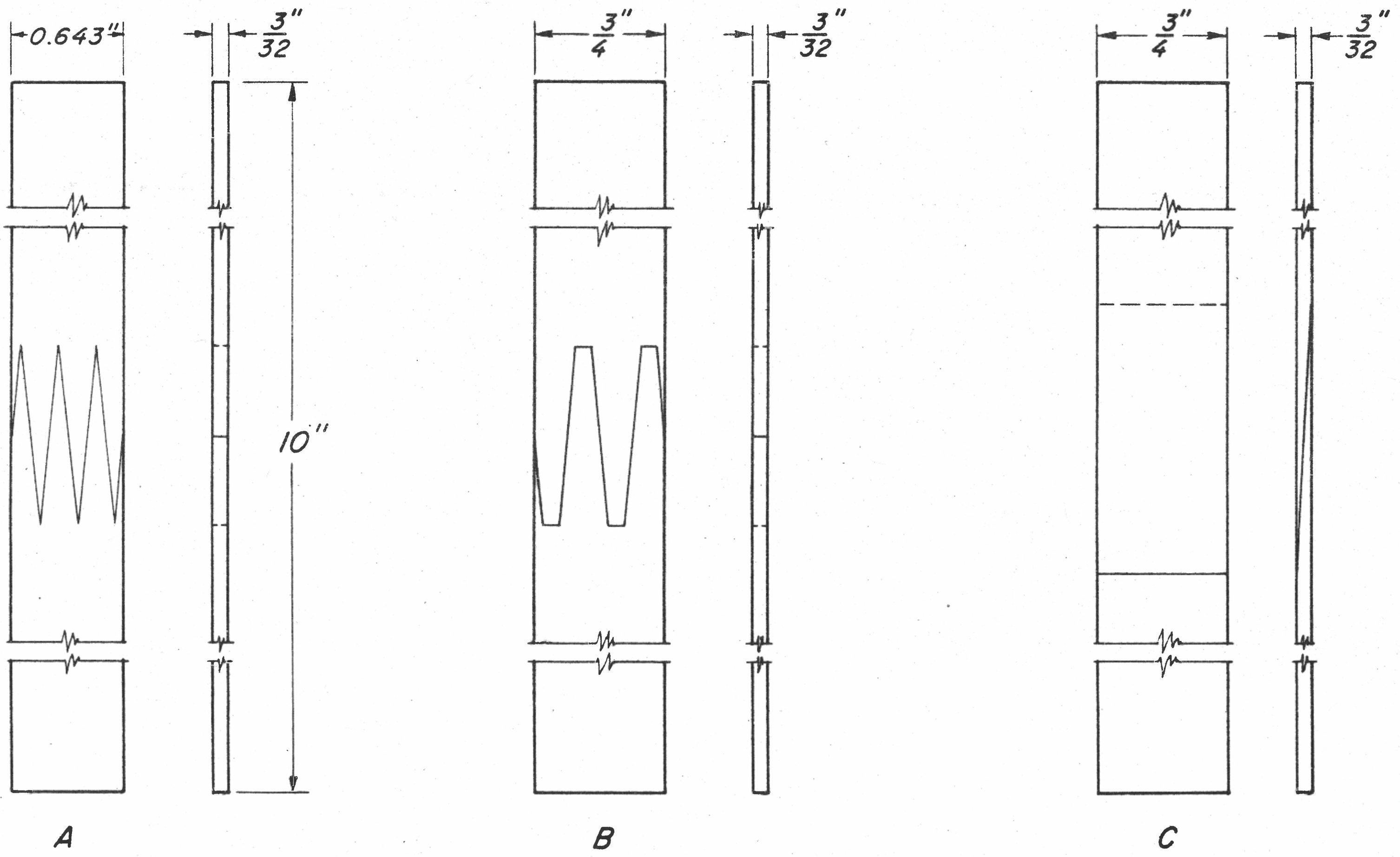

Figure 5. --Tension test specimens for quality control of glue bonds in finger joints (A and B) and scarf joints (C).