END JOINTS OF VARIOUS TYPES IN
DOUGLAS-FIR AND WHITE OAK
COMPAReD FOR STRENGTH

Information Reviewed and Reaffirmed

December 1961

No. 1622
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DOUGLAS-FIR AND WHITE OAK COMPARED FOR STRENGTH

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Summary

The growing scarcity of large structural members of suitable quality is rapidly leading to an increase in the use of glued laminated members. Structural members are often of such length that end joints in laminations are necessary. Little is known of the strength of various types of joints, and it was the purpose of this study, performed at the Forest Products Laboratory, to obtain such information.

Both Douglas-fir and white oak were used in the study. The types of joints investigated included: plain scarf joints of slopes of 1 in 3, 1 in 6, 1 in 10, 1 in 12, 1 in 15, and 1 in 20, serrated scarf joints, square-toothed scarf joints, fingered joints, and "Onsrud" joints. Tension and compression strengths parallel to the grain were determined.

For each specimen with a joint a carefully matched control specimen was tested. The tension specimens with plain scarf joints and the corresponding control specimens had a minimum cross section of 1/4 by 1/2 inch and were so shaped that the 1/2-inch dimension was radial to the growth rings to include the maximum number of annual rings. The minimum section of the tension specimens with serrated scarf, square-toothed scarf, fingered, and

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1 In cooperation with the Office of Production Research and Development, War Production Board. Report originally dated August 1946.

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

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Onsrud joints was 3/4 by 1 or 1-1/8 inches. The corresponding controls were of the same shape as specimens with plain scarf joints.

The compression tests were made on specimens with serrated scarf, square-toothed scarf, and fingered Onsrud joints and on corresponding controls. These were approximately 3/4 by 1-3/4 inches in cross section and about 4 inches long.

The serrated scarf, square-toothed scarf, Onsrud, and most fingered joints were made by Gamble Brothers of Louisville, Kentucky. A few of the fingered joints were made by the Speedwall Division of Timber Structures, Inc., Seattle, Washington. The plain scarf joints were made either at the Laboratory using a resorcinol glue hardened with formaldehyde or at the Speedwall Division of Timber Structures, Inc., Seattle, Washington, using a resorcinol glue hardened with paraform and under the supervision of a Laboratory representative.

The plain scarf joints varied greatly in tensile strength. Douglas-fir with a scarf joint of slope of 1 in 3 was on the average deficient by 45 percent; those with a slope of 1 in 6, about 23 percent; those with a slope of 1 in 10, about 10 percent; and those with a slope of 1 in 20 about 5 percent compared to corresponding controls. Similarly, white oak with plain scarf joints of a slope of 1 in 3 was on the average deficient by about 60 percent; those with a slope of 1 in 6, about 27 percent; those with a slope of 1 in 10, about 14 percent; and those with a slope of 1 in 20, about 5 percent.

That an efficiency of 100 percent in tension may be impossible even with very flat slopes is indicated by the fact that specimens with plain scarf joints sloping at 1 in 20 failed at lower stresses than the matched controls, although practically none of the failures were in the joint. The same conclusion is suggested by the fact that in an end joint part of the cross-sectional area of the summerwood, which is of high strength, is joined to springwood, which is much lower in strength. Similar reasoning would apply to the strength in shear parallel to the grain of a glued joint between two pieces of edge-grained lumber and to end joints in longitudinal compression. It is most valid for coniferous woods and ring-porous hardwoods in both of which the annual layers consist of two parts differing in structure and density.

The serrated scarf, square-toothed scarf, fingered, and Onsrud joints were all less efficient in tensile strength than a plain scarf joint of a slope of 1 in 10 or flatter. The serrated joints had an efficiency of about 50 to 75 percent, the Onsrud joints only about 25 percent, and the fingered joints 20 to 45 percent depending upon the type. These several types of joints have as their purpose the saving of lumber by reducing the length of joint, together with avoidance of the necessity of applying lateral or transverse pressure by clamps or press during the curing of the glue. Some of them, such as the
fingered types, are obviously deficient in strength because of the ineffectiveness of the parts of the cross section at the ends of the fingers.

The compression strengths of serrated, square toothed, and Onsrud joints in both Douglas-fir and white oak were close to 100 percent. The fingered joints were also close to 100 percent for white oak in this property and about 75 percent efficient for Douglas-fir compared to corresponding controls.

Introduction

The use of glued laminated structural members is rapidly increasing because of the growing scarcity of large structural timbers of suitable quality. These members are frequently of such length that end joints in the laminations are necessary. Various types of end joints have been used, but little is known of their relative merits.

It was the purpose of this study to determine the strength of several commonly-used end joints. End joints in the bottom or top laminations in glued laminated beams of considerable depth are subjected to almost pure tension and compression, and since this study was made in connection with tests of glued laminated beams of 12-inch depth, the tensile and compressive strengths were the properties chosen for study.

It is much more difficult to make an end joint that will give satisfactory performance when subjected to tensile stresses than when it is stressed in compression. Consequently, most of the tests included in this study were to determine the strength in tension parallel to the grain.

Material

The material used in this study included Douglas-fir and white oak. All of the white oak was obtained from stock at the Laboratory; part was flat sawn and part quarter-sawn.

The Douglas-fir consisted of: (1) forty boards sawed at the Laboratory from two logs of somewhat lower specific gravity than the average for the species; (2) five boards from the Speedwall Division of Timber Structures, Inc., Seattle, Washington; and (3) forty-eight boards from Timber Structures, Inc., Portland, Oregon. The boards from Portland, Oregon, were selected to be representative of the quality of the stock available, and their average specific gravity was about equal to the average for the species.
The schedule of tests (table 1) shows the number and types of specimens tested, grouped according to source of material.

All material was dried to about 11 percent moisture content.

Fabrication of Test Specimens

**Douglas-fir and white oak (Series 1 and 2)**

Figure 1 shows the method of matching the specimens to be tested for strength in tension parallel to the grain.

The Douglas-fir boards were first cross cut into 30-, 27-, and 37-inch lengths and the white oak boards into 30-, 32-, and 38-inch lengths. The 30-inch lengths were used for specimens with serrated scarf, square-toothed scarf, fingered, or Onsrud joints. Three specimens were obtained from each board.

The 27-inch lengths of the Douglas-fir and 32-inch lengths of white oak boards were used for control specimens. Five specimens were obtained from each board.

The 37-inch length of each Douglas-fir board and 38-inch length of each white oak board furnished five test blanks for specimens with plain scarf joints of five different slopes.

Other Douglas-fir and white oak boards were used for compression tests of specimens with serrated scarf, square-toothed scarf, fingered, or Onsrud joints and corresponding controls as shown in figure 2. These were not matched to the boards from which tension specimens were obtained.

All serrated scarf, square-toothed, Onsrud, and fingered joints, as detailed in figures 3, 4, 5, and 6, were made in boards about 6 inches wide by Gamble Brothers, Louisville, Kentucky. The boards sent to Gamble Brothers were all of 30-inch length, as joints cannot be made in boards of shorter length with their equipment. The joints were glued with a resorcinol glue hardened with formaldehyde (glue A).

As previously mentioned, the portions of each board of series 1 and 2 furnished five specimens, 37 or 38 inches in length, to be tested in tension parallel to the grain. Each specimen had a different slope of plain scarf joint. It was necessary, therefore, first to rip each such length into five equal parts. Each test blank was then cut diagonally across the edge-grained face, which
was made the wider face of the finished specimen as shown in figures 7 and 8. In this way the maximum number of annual rings of growth were represented in the finished specimen making it more representative of average material.

Preparatory to gluing, the surfaces of each scarf joint were machined smooth on a vertical-spindle shaper equipped with a collar knife. The joints were glued with glue A without sizing prior to gluing. A pressure of 150 pounds per square inch for the Douglas-fir and 175 pounds per square inch for the white oak test blanks was applied uniformly over each joint for a period of 8 hours or more, with the material at room temperature. These test blanks were end blocked during the pressing operation to prevent slippage. A lap sufficient to produce a total thickness 1/64 inch greater than the thickness of the test blank was made to insure complete pressure over the entire surface of each joint. After gluing and pressing, the test blanks were cured without pressure in a kiln for a period of at least 10 hours at a dry bulb temperature of 140° F., and a 12 percent equilibrium moisture content condition. The blanks were later made into specimens to be tested in tension parallel to the grain of the size and shape shown in figures 7B and 8B.

The Douglas-fir tension specimens with scarf joints differed in the length of the central section of minimum cross section from the corresponding control specimens, this section being 14-1/2 inches long in specimens with scarf joints and only 5 inches long in control specimens, as illustrated in figure 7.

In the tests, failure often occurred at local irregularities in this minimum section. Thus the scarf-jointed specimens with the longer central length of minimum cross section were more likely to have lower tensile strength caused by local irregularities of grain than corresponding controls with shorter central section of minimum cross section. As a result of this experience the length of the central portion with uniform cross section was made the same in the control and the plain scarf-jointed specimens of white oak (fig. 8). The length of the uniform section was made 12 inches rather than 14-1/2 inches as in the Douglas-fir specimens because 1 inch of uniform section beyond the ends of the longest plain scarf joint, slope, 1:20, seemed to be ample.

**Douglas-fir (Series 3)**

The division of the five Douglas-fir boards with fingered joints received from the Speedwall Division, Timber Structures, Inc., Seattle, Washington, into tension, compression, and specific gravity specimens is shown in figure 9. The fingered joints made by Timber Structures, Inc., differed from those made by Gamble Brothers, in that the fingers passed through the width of the
board (fig. 10) rather than through the thickness (fig. 5). There were differences also in the lengths and cross-sectional dimensions of the fingers. Where cross grain existed in the boards, the tension control specimens were oriented with the grain direction. No attempt was made to eliminate cross grain in any of the other specimens, since this procedure would have changed the position of the joints in the specimens. The tension specimens containing the fingered joints were sized to the dimensions shown in figure 11. The details for the control specimens are shown in figure 7. The compression specimens were 1-3/4 inches wide by 4 inches long and approximately 3/4 inch thick (fig. 12).

**Douglas-fir (Series 4 and 5)**

The 36 boards obtained from Timber Structures, Inc., Portland, Oregon, for further study of plain scarf joints were divided into 6 groups. The grouping was by specific gravity, each group covering about the same range in specific gravity as nearly as could be done with the scales available. It was not practical to rip these boards first and then make a plain scarf joint of different slope in each test blank from a given board, as was done at the Laboratory. All boards of a single group had a scarf joint of the same slope placed about 25 inches from the end. The slopes were 1:3, 1:6, 1:10, 1:12, 1:15, and 1:20. The scarfs were made at the Speedwall Division of Timber Structures, Inc., Seattle, Washington. The gluing was done under the supervision of a Laboratory representative, and a resorcinol glue hardened with paraform (glue B) was used.

The tension specimens with the plain scarf joints and matched control specimens were fabricated at the Laboratory. The layout of the specimens within a board and the details of the finished specimens are shown in figures 13A and 8. Extra material was glued to the wide surfaces of the 3/4-inch boards to furnish the required 1-inch depth in the radial direction at the grip ends of the specimens.

Additional material consisting of two groups of Douglas-fir boards of six each were selected at Portland, Oregon, from stock intended for a laminated glued beam study also in progress at the Laboratory. These were sent to Gamble Brothers, Louisville, Kentucky, where serrated scarfs (fig. 14) were made in one group, and Onsrud joints (fig. 15) in the other. These were sent to the Laboratory where they were fabricated into test specimens. The method of matching is shown in figure 13B, the type of test specimen with joint in figure 11, and the control specimen in figure 7A.
Reinforcement of Douglas-fir tension specimens

Preliminary tests showed that Douglas-fir specimens needed reinforcement at the grips to prevent a crushing failure by the grips during test. This was accomplished with 1/8-inch staypak or white oak inserts, the grain of which was perpendicular to the wide face of the specimens (fig. 11). Long oak caps were also glued to the wide faces of the specimens at the ends to prevent shear or tension failures near the grips. No staypak inserts or oak caps were used for the white oak specimens, as the white oak was sufficiently high in compressive strength perpendicular to the grain to prevent crushing at the grips.

Conditioning of specimens

Prior to test all specimens were conditioned to equilibrium moisture content at a temperature of 75° F., and 64 percent relative humidity.

Marking of specimens

Each board was assigned a number starting with 1, to which were suffixed letters to designate species and grain. The letters W and D referred to white oak and Douglas-fir, respectively, and the letters P and Q referred to plain-sawed and quarter-sawed. The specimens cut from the boards were assigned these numbers and letters along with a number from 1 to 5, depending on their position in the board with reference to one edge, and a letter to describe the specimen. Letters S, A, F, N, P, C, and G referred to, respectively, serrated scarf, square-toothed scarf, fingered, Onsrud, plain scarf, control, and specific gravity.

In the plain scarf-jointed specimens, a number was suffixed to the letter P to indicate the slope of the scarf joint. For example, a specimen numbered 6DP-4F15 came from the plain-sawed Douglas-fir board No. 6, was the fourth specimen from the edge of a board, and contained a plain scarf joint having a slope of 1 in 15.

Method of Testing

Tension parallel to grain

All specimens tested in tension parallel to the grain were tested with the machine head traveling at the rate of 0.05 inch per minute until failure.
Tension grips having spherically seated end connections were used for all tests (figs. 16 and 17). Only the maximum load was recorded.

Compression parallel to grain

Specimens tested in compression parallel to the grain were loaded through a spherical bearing block which prevented eccentricity of loading. The rate of fiber strain under compression load was 0.003 inch per minute per inch of specimen length; that is, for a specimen 4 inches long the rate of loading was 0.012 inch per minute. The load was applied to each specimen continuously past the maximum load until visual failure had occurred.

Explanation of Tables and Charts

Table 1 is a schedule of tests of Douglas-fir and white oak specimens with various types of end joints and corresponding control specimens tested in tension and compression parallel to the grain. The types of joints include plain scarf of slopes of 1:3, 1:6, 1:10, 1:12, 1:15, and 1:20, serrated scarf, square-toothed scarf, Onsrud, and two types of fingered scarf. Information on kinds of glue used, source of material, and name of fabricator of the end joints is also included. The number of specimens in table 1 is sometimes higher than shown in tables 2 and 3, since certain specimens failed at defects, such as small knots and irregular grain which likely affected the load sustained, and values from such specimens were not included in the tables of strength values. Table 2 includes strength and related data for tests in tension and compression parallel to the grain on white oak and Douglas-fir specimens with end joints of various types and corresponding control specimens. Average, maximum, and minimum values are shown for each type of joint and species.

Table 3 includes ratios of strength values in tension and compression parallel to the grain of white oak and Douglas-fir specimens with end joints to the strength values of those without joints. Ratios are shown which are based on average of all tests for each specific type of joints; and also average of ratios based on individually matched pairs for a given type of joint together with maximum and minimum ratios.

Figures 1, 2, 9, and 13 are cutting diagrams of blanks for specimens to be tested in tension and compression parallel to the grain from Douglas-fir and white oak boards. Figures 7, 8, and 11 show details of the various types of specimens used in this investigation for tests in tension parallel to the grain. Figure 12 shows details of the specimens tested in compression parallel to the grain.

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Figures 3, 4, 5, 6, 10, 14, and 15 show details of serrated scarf, square-toothed scarf, Onsrud, and fingered joints. Figures 3, 4, and 14 all show a similar type of joint differing primarily in the shape of the serrations. Figures 5 and 10 both show details of fingered joints, but differ in that figure 5 shows fingers through the face board and figure 10 the fingers are in the edge of the board. Figures 6 and 15 both detail Onsrud joints which differ slightly in that the joint in figure 6 has two complete and two one-half multiples of cut, while the joint in figure 15 has three complete multiples of cut.

Figures 16 and 17 show machine set-ups for tests to determine strength in tension parallel to the grain.

The maximum strength in tension parallel to the grain of Douglas-fir specimens with plain scarf joints of various slopes as related to corresponding controls is shown in figure 18. Individual ratios for matched specimens with and without joints are plotted, and the curve is based on the average of these ratios. Figure 19 is a similar graph but for white oak.

Figure 20 also shows the relationship of the strength of plain-scarf-jointed specimens with various slopes to corresponding controls, but differs from figures 18 and 19 in that the curves in figure 20 are based on ratios of averages rather than average of ratios.

There was considerable variation in the specific gravity of the Douglas-fir specimens and white oak specimens tested. Figures 21 and 22 show the effect of specific gravity on the strength in tension parallel to the grain of specimens with scarf joints; they also show how the ratios of specimens with scarf joints and corresponding controls are affected by specific gravity.

The relationship of the strength in tension parallel to the grain of specimens without joints to specific gravity is shown in figure 23. Individual strength values for corresponding specific gravity values were plotted. Parabolic curves of the form $y = ax^b$ were fitted to the plotted points where the strength and specific gravity (y and x) values are assumed mutually dependent (equally in error). Suitable powers for specific gravity were computed by the method of least squares using the formula:

$$b = \frac{\Sigma \log y_1^2 - \Sigma \log x_1 \log y_1}{2 \Sigma \log x_1 \log y_1}$$

where $\log y_1$ and $\log x_1$ are deviations from the means of logs of strength and specific gravity, respectively, and
\[ \log a = \frac{\sum \log y - b \sum \log x}{N} \]

where \( y \) and \( x \) are strength and specific gravity values, respectively, and \( a \) and \( b \) are constants.

Figures 24 and 25 show the strength in tension and compression parallel to the grain of Douglas-fir and white oak specimens with serrated scarf, square-toothed scarf, Onsrud, and fingered joints compared to corresponding controls.

Figures 26 to 38, inclusive, show typical failures of specimens.

**Discussion of Results**

**Plain scarf joints in Douglas-fir**

The relation of slope of plain scarf joint to the strength of Douglas-fir in tension parallel to the grain is shown in figures 18 and 20. In figure 18 ratios for individual matched pairs of specimens with and without scarf joints are plotted. The curve is based on averages of ratios and shows that specimens with scarf joints having a slope as gradual as 1 in 20 averaged about 5 percent lower in strength in tension parallel to the grain than matched specimens without joints. Increasing the slope of scarf to 1 in 15 left the average strength ratio about the same. At a slope of 1 in 10 the curve indicates a decrease in strength of about 10 percent. Similarly the decrease in strength for a slope of 1 in 6 was about 23 percent, and that for a slope of 1 in 3 was about 45 percent.

Although the individual pairs of specimens with and without scarf joints were carefully matched for quality, the ratios of strength values for individual pairs showed a wide range, and frequently, especially for the more gradual slopes of scarfs, the ratios were over 100 percent. Even the average of the ratios for specimens with a slope of scarf of 1 in 12 was over 100 percent. This average, however, was based on relatively few specimens and, hence, was given less consideration than average values for other slopes of scarf.

Typical types of failure differed markedly for specimens with scarf joints of gradual and steep slopes, those with steep slopes usually failing in the glue joint and those with gradual slopes usually failing outside or away from the joint as shown in figures 26 and 28. The plotted ratios for individual pairs have been represented by two symbols, the open circle indicating that failure
was away from the joint and the small x that failure was in the joint or that the joint obviously contributed to the failure.

Most of the failures for specimens with scarf joints of a slope of 1 in 20 failed away from the joint, but still the average strength ratio of specimens with a scarf joint and without was below 100 percent, indicating that even at very gradual slopes of scarf some slight decrease in strength can be expected. This may possibly be explained as follows: In the process of end joining two pieces of wood the summerwood portion of the annual growth layers, which are high in strength, and the springwood portions, which are low in strength, are not well aligned. Thus, parts of the summerwood may be end-joined to parts of the springwood and the resulting strength could conceivably be less than for uncut pieces. The number of failures at joints increased with an increase in the slope of the scarf, and for a slope of 1 in 3 practically all failures occurred in the glue joint.

Plain scarf joints in white oak

Information on the effect of the slope of the scarf on the strength of white oak in tension parallel to the grain is included in figures 19 and 20. This effect, as indicated in figure 19, is similar to that for Douglas-fir, as shown in figure 18, but is usually somewhat more pronounced. For a slope of 1 in 20 the reduction is about 5 percent, which is the same as for Douglas-fir; but for a slope of 1 in 15 the reduction is about 8 percent, for a slope of 1 in 10 about 14 percent, for a slope of 1 in 6 about 27 percent, and for a slope of 1 in 3 nearly 60 percent. It is apparent that it is more difficult to obtain high strength ratios for white oak than for Douglas-fir, which is probably due to the higher specific gravity and strength of white oak.

As with Douglas-fir the type and placement of failure varied with the slope of grain. The failure for a slope of scarf of 1 in 20 was consistently away from the joint, and the steeper slopes of scarf the failure occurred more frequently at the joint until for a slope of scarf of 1 in 3 practically all failures occurred at the joint, as shown in figure 30.

The individual strength ratios for matched pairs of white oak also showed considerable variation for any given slope, but the variation was not as great as for Douglas-fir.

The effect of slope of plain scarf joints in Douglas-fir and white oak, as shown in figure 20, is similar to that shown in figures 18 and 19. Figure 20 differs from figures 18 and 19 in that each plotted point of figure 20 is the ratio of the average value for all specimens with a given slope of grain and corresponding controls; whereas in figures 18 and 19 ratios for
individually matched pairs are plotted. With a representative number of specimens similar curves by the two methods are to be expected.

Representative material for control specimens

The strength of wood in tension parallel to the grain is highly susceptible to small defects, and even slight deviation of grain from the central axis of a test specimen has a marked effect on its strength. It seemed possible that the strength values of the control specimens were not truly representative of the inherent strength of the wood and that this might account in part for the large variations in the ratios of individually matched pairs of specimens with joints of a given slope and corresponding controls.

In figure 23 the strength values for Douglas-fir and white oak in tension parallel to the grain are plotted against specific gravity. The grouping of the points is as good as would be expected for fully representative material free of defects. These graphs for Douglas-fir and white oak indicate that the specimens without joints for strength tests in tension parallel to the grain, which were the control specimens for specimens with scarf joints, were representative for the species, and that the large range in strength ratios for specimens with and without joints is not caused by nonrepresentative material.

Specific gravity-strength relation

The relation of maximum strength in tension parallel to the grain to specific gravity for Douglas-fir specimens with the same slope of scarf is shown in figure 21. The efficiency of a slope of scarf of 1 in 3 is so low that no increase in strength accompanies an increase in specific gravity. This effect is further emphasized by the fact that 35 out of 37 specimens failed in the joint.

For specimens with a slope of scarf of 1 in 6 the strength in tension parallel to the grain is greater for those specimens with higher specific gravity, indicating that the effect of the scarf joint is less than for those specimens with a slope of scarf of 1 in 3. Another indication of the lesser effect of a slope of scarf of 1 in 6 is that only 5 out of 11 specimens in the group with lower specific gravity failed at the joint; the number for the specimens in the group with mid-range specific gravity was 8 out of 13; while all 13 failed at the joint in the group with the highest specific gravity. By similar reasoning it is shown that the effect of scarf becomes less important with flatter slopes, but those specimens with high specific gravity remain more likely to fail at the joint than those with lower specific gravity.
As shown in the lower sets of groups in figure 21 the ratio of maximum strength of specimens in tension parallel to the grain with and without scarf joints decreases for increased specific gravity for those specimens with a slope of 1 in 3 and 1 in 6. Since the upper sets of graphs show that no increase in strength in tension parallel to the grain is obtained for increased specific gravity for specimens with a slope of scarf joint of 1 in 3, and only slightly for specimens with a slope of 1 in 6, the decreasing ratio of maximum strength in tension parallel to grain of specimens with scarf joints with these slopes to corresponding controls is to be expected. For specimens with scarf joints of lesser slope there appears to be a slight increase in the ratio of the strength of specimens with scarf joints in tension parallel to the grain and corresponding controls for increased specific gravity. The one exception is for the group of specimens with a slope of 1 in 12 having the lowest specific gravity, and this plotted point is represented by only two specimens.

A similar comparison of white oak specimens can be obtained from graphs in figure 22. These graphs are based on fewer tests and the trends are not so well defined.

Serrated scarf, square-toothed scarf, fingered, and Onsrud joints

In addition to the tests of specimens with plain scarf joints of various slopes, tests of Douglas-fir and white oak specimens with serrated scarf, square-toothed scarf, fingered, and Onsrud joints were tested in tension and compression parallel to the grain. The results of these tests are shown in figures 24 and 25. Of the Douglas-fir specimens tested in tension parallel to the grain, those with square-toothed scarf joints showed the highest efficiency ratio. Those with serrated scarf joints, as illustrated in figure 14, were next in order. It may be noted that these tests came from two different series and from two lots of material and inherent strength in tension parallel to the grain and also the specific gravity for specimens with serrated scarf joints, as detailed in figure 14, were actually higher than for those specimens with square-toothed scarf joints (table 2). The sides of the teeth in the square-toothed joint are parallel, while the side walls of the serrated joint detailed in figure 14 have a slight taper. Due to the resulting wedging action and better contact of the assembled serrated joint, a better glue joint should result than in a square-toothed joint. It is quite likely, therefore, that the strength ratio of 72 for the square-toothed scarf joint and 64 for the serrated joint as detailed in figure 14 differ more than would result with well-matched material.

The serrated scarf joint as detailed in figure 3 has much greater slope of side walls than for that of figure 14. Because it is more difficult to cut
smoothly and harder to fit, a lower strength ratio (57 percent) is to be expected for the serrated joint of figure 3 than for that of figure 14.

The fingered joint as detailed in figure 5 has an efficiency ratio slightly less than 50 percent. The Onsrud joints detailed in figures 6 and 15 have efficiencies of 25 and 34 percent, respectively; while the fingered joint detailed in figure 10 has an efficiency of only 18 percent.

Fewer types of joints in white oak specimens were tested. The efficiencies (slightly over 50 percent) of the serrated and square-toothed scarf joints in white oak were similar and somewhat lower than for Douglas-fir. The efficiencies of fingered joints and Onsrud joints in white oak were nearly the equal of those of Douglas-fir.

End joints have much less effect on strength in compression parallel to the grain than on strength in tension parallel to the grain. Figure 25 shows that serrated scarf, square-toothed scarf, and Onsrud joints in both Douglas-fir and white oak were practically the equal of the control specimens. The fingered joints in Douglas-fir caused an average reduction in strength in compression parallel to the grain of 20 to 25 percent, while in white oak no reduction was apparent.

Conclusions

1. Plain scarf joints with a slope of only 1 in 20 caused a reduction of about 5 percent in strength in tension parallel to the grain in both Douglas-fir and white oak. Practically none of the failures occurred in the glue joint indicating that it may be impossible to get 100 percent efficiency with any reasonable slope.

2. Increasing the slope of the scarf caused larger reductions in strength. For Douglas-fir the decrease in strength in tension parallel to the grain for slopes of 1 in 10, 1 in 6, and 1 in 3 were about 10, 23, and 45 percent, respectively. For white oak the decrease in strength in tension parallel to the grain for slopes of 1 in 10, 1 in 6, and 1 in 3 were about 14, 27, and 60 percent, respectively.

3. The maximum strength in tension parallel to the grain of specimens with slope of scarf of 1 in 3 did not increase with increase in specific gravity. Some increase was obtained when the slope of scarf was 1 in 6, and greater increases were found for lesser slopes.
4. The several commercial types of scarf joints used, such as serrated, fingered, and Onsrud, were all less efficient in strength in tension parallel to the grain than plain scarf joints of a slope of 1 in 10 or flatter.

5. Of the several types of commercially used joints the serrated types were strongest in tension parallel to the grain (50 to 75 percent efficient); the fingered joints with fingers through the face of the board were about 45 percent efficient; Onsrud joints were 25 to 35 percent efficient; and fingered joint with fingers through the edge of the boards were about 20 percent efficient.

6. The efficiency of serrated, fingered, and Onsrud joints in compression parallel to the grain was high. In white oak these joints had 95 to 100 percent efficiency; in Douglas-fir the serrated and Onsrud joints were nearly 100 percent efficient, while the fingered joints were about 75 percent efficient.
Table 1.—Schedule of tension- and compression-parallel-to-grain tests of end joints of various types

<table>
<thead>
<tr>
<th>Species</th>
<th>Type of end joint</th>
<th>Fabricator of end joint</th>
<th>Board numbers</th>
<th>Number of tests</th>
<th>Tension</th>
<th>Compression</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>parallel to grain</td>
<td>parallel to grain</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>End : Matched</td>
<td>End : Matched</td>
</tr>
<tr>
<td>Douglas-fir</td>
<td>Serrated scarf</td>
<td>Gamble Bros., Louisville, Ky.</td>
<td>1D to 5D, incl.</td>
<td>15 : 25</td>
<td>15 : 25</td>
<td>15 : 25</td>
</tr>
<tr>
<td>Do.</td>
<td>Square-toothed scarf</td>
<td>Gamble Bros.</td>
<td>6 to 100, incl.</td>
<td>15 : 25</td>
<td>15 : 25</td>
<td></td>
</tr>
<tr>
<td>Do.</td>
<td>Fingered</td>
<td>Gamble Bros.</td>
<td>11D to 15D, incl.</td>
<td>15 : 25</td>
<td>15 : 25</td>
<td></td>
</tr>
<tr>
<td>Do.</td>
<td>Marud</td>
<td>Forest Products Laboratory</td>
<td>1D to 20D, incl.</td>
<td>15 : 25</td>
<td>15 : 25</td>
<td></td>
</tr>
<tr>
<td>Do.</td>
<td>Plain scarf, slope 1:3</td>
<td>Marud</td>
<td>16D to 20D, incl.</td>
<td>15 : 25</td>
<td>15 : 25</td>
<td></td>
</tr>
<tr>
<td>Do.</td>
<td>Fingered</td>
<td>Gamble Bros.</td>
<td>6 to 100, incl.</td>
<td>15 : 25</td>
<td>15 : 25</td>
<td></td>
</tr>
<tr>
<td>Do.</td>
<td>Serrated scarf</td>
<td>Gamble Bros., Louisville, Ky.</td>
<td>21D to 25D, incl.</td>
<td>15 : 25</td>
<td>15 : 25</td>
<td></td>
</tr>
<tr>
<td>Do.</td>
<td>Square-toothed scarf</td>
<td>Gamble Bros.</td>
<td>6 to 100, incl.</td>
<td>15 : 25</td>
<td>15 : 25</td>
<td></td>
</tr>
<tr>
<td>Do.</td>
<td>Fingered</td>
<td>Gamble Bros.</td>
<td>11D to 15D, incl.</td>
<td>15 : 25</td>
<td>15 : 25</td>
<td></td>
</tr>
<tr>
<td>Do.</td>
<td>Marud</td>
<td>Forest Products Laboratory</td>
<td>1D to 20D, incl.</td>
<td>15 : 25</td>
<td>15 : 25</td>
<td></td>
</tr>
<tr>
<td>Do.</td>
<td>Plain scarf, slope 1:3</td>
<td>Marud</td>
<td>16D to 20D, incl.</td>
<td>15 : 25</td>
<td>15 : 25</td>
<td></td>
</tr>
<tr>
<td>Series 1 — Source: Forest Products Laboratory, Glue A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White oak</td>
<td>Serrated scarf</td>
<td>Gamble Bros., Louisville, Ky.</td>
<td>1F to 5F, incl.</td>
<td>15 : 25</td>
<td>15 : 25</td>
<td></td>
</tr>
<tr>
<td>Do.</td>
<td>Square-toothed scarf</td>
<td>Gamble Bros.</td>
<td>6F to 10F, incl.</td>
<td>15 : 25</td>
<td>15 : 25</td>
<td></td>
</tr>
<tr>
<td>Do.</td>
<td>Fingered</td>
<td>Gamble Bros.</td>
<td>11F to 15F, incl.</td>
<td>15 : 25</td>
<td>15 : 25</td>
<td></td>
</tr>
<tr>
<td>Do.</td>
<td>Marud</td>
<td>Forest Products Laboratory</td>
<td>1F to 20F, incl.</td>
<td>15 : 25</td>
<td>15 : 25</td>
<td></td>
</tr>
<tr>
<td>Do.</td>
<td>Plain scarf, slope 1:3</td>
<td>Marud</td>
<td>16F to 20F, incl.</td>
<td>15 : 25</td>
<td>15 : 25</td>
<td></td>
</tr>
<tr>
<td>Series 2 — Source: Forest Products Laboratory, Glue B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Douglas-fir</td>
<td>Fingered</td>
<td>Speedwood Division, Timber Structures, Inc.</td>
<td>1F to 5F, incl.</td>
<td>15 : 25</td>
<td>15 : 25</td>
<td></td>
</tr>
<tr>
<td>Do.</td>
<td>Plain scarf, slope 1:20</td>
<td>Speedwood Division, Timber Structures, Inc.</td>
<td>1F to 5F, incl.</td>
<td>15 : 25</td>
<td>15 : 25</td>
<td></td>
</tr>
<tr>
<td>Do.</td>
<td>Fingered</td>
<td>Speedwood Division, Timber Structures, Inc.</td>
<td>1F to 5F, incl.</td>
<td>15 : 25</td>
<td>15 : 25</td>
<td></td>
</tr>
<tr>
<td>Do.</td>
<td>Serrated scarf</td>
<td>Speedwood Division, Timber Structures, Inc.</td>
<td>1F to 5F, incl.</td>
<td>15 : 25</td>
<td>15 : 25</td>
<td></td>
</tr>
<tr>
<td>Series 3 — Source: Seattle, Wash. Glue B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Douglas-fir</td>
<td>Fingered</td>
<td>Speedwood Division, Timber Structures, Inc.</td>
<td>1T to 10T, incl.</td>
<td>15 : 25</td>
<td>15 : 25</td>
<td></td>
</tr>
<tr>
<td>Do.</td>
<td>Plain scarf, slope 1:20</td>
<td>Speedwood Division, Timber Structures, Inc.</td>
<td>1T to 10T, incl.</td>
<td>15 : 25</td>
<td>15 : 25</td>
<td></td>
</tr>
<tr>
<td>Do.</td>
<td>Fingered</td>
<td>Speedwood Division, Timber Structures, Inc.</td>
<td>1T to 10T, incl.</td>
<td>15 : 25</td>
<td>15 : 25</td>
<td></td>
</tr>
<tr>
<td>Do.</td>
<td>Serrated scarf</td>
<td>Speedwood Division, Timber Structures, Inc.</td>
<td>1T to 10T, incl.</td>
<td>15 : 25</td>
<td>15 : 25</td>
<td></td>
</tr>
<tr>
<td>Series 4 — Source: Portland, Ore. Glue B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: The specimens without joints from Douglas-fir boards 1 to 20, inclusive, and white oak boards 1 to 20, inclusive, served as controls for both the commercially patented end joints and plain scarf joints.
<table>
<thead>
<tr>
<th>Type of end joint</th>
<th>Specimen</th>
<th>Ratio of strength of jointed to control specimens based on matched pairs of specimens</th>
<th>Matched boards</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Tension-Parallel-To-Grain</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Compression-Parallel-To-Grain</td>
<td></td>
</tr>
</tbody>
</table>

Each board furnished three specimens with joints and five controls — ratios therefore based on average of specimens from a board rather than matched pairs.
NOTE: ALL FLAT SAWED BOARDS WERE 1/4" THICK AND THE QUARTER SAWED BOARDS WERE 1" OR LESS IN THICKNESS DEPENDING ON THE THICKNESS OF THE MATERIAL FROM WHICH THE BOARDS WERE OBTAINED.

### (DOUGLAS-FIR BOARDS, SERIES 1)

<table>
<thead>
<tr>
<th>2DP-15</th>
<th>2DP-1C</th>
<th>2DP-1P3</th>
</tr>
</thead>
<tbody>
<tr>
<td>2DP-25</td>
<td>2DP-2C</td>
<td>2DP-2P6</td>
</tr>
<tr>
<td>2DP-35</td>
<td>2DP-3C</td>
<td>2DP-3P10</td>
</tr>
<tr>
<td></td>
<td>2DP-4C</td>
<td>2DP-4P15</td>
</tr>
<tr>
<td></td>
<td>2DP-5C</td>
<td>2DP-5P20</td>
</tr>
</tbody>
</table>

30" (25" NET) 27" 37" (32½" NET)

94"

(JOINTS MADE AT GAMBLE BROS)

- SERRATED SCARF
- SQUARE TOOTHED SCARF
- FINGERED AND ONSRUD JOINTED SPECIMENS

(JOINTS MADE AT F.P.L.)

- CONTROL SPECIMENS

<table>
<thead>
<tr>
<th>3WQ-1A</th>
<th>3WQ-1C</th>
<th>3WQ-1P10</th>
</tr>
</thead>
<tbody>
<tr>
<td>3WQ-2A</td>
<td>3WQ-2C</td>
<td>3WQ-2P15</td>
</tr>
<tr>
<td>3WQ-3A</td>
<td>3WQ-3C</td>
<td>3WQ-3P20</td>
</tr>
<tr>
<td></td>
<td>3WQ-4C</td>
<td>3WQ-4P3</td>
</tr>
<tr>
<td></td>
<td>3WQ-5C</td>
<td>3WQ-5P6</td>
</tr>
</tbody>
</table>

30" (25" NET) 32" 38" (32½" NET)

100"

(white oak boards, series 2)

Figure 1.--Cutting diagram for specimens to be tested in tension parallel to the grain from Douglas-fir and white oak boards.
NOTE: ALL FLAT SAWED BOARDS WERE 1/8" THICK AND THE QUARTER SAWED BOARDS WERE 1/4 OR LESS IN THICKNESS DEPENDING ON THE THICKNESS OF THE MATERIAL FROM WHICH THE BOARDS WERE OBTAINED.

(SPECIFIC GRAVITY SPECIMENS)

(SERRATED SCARF)

(SQUARE TOOTHED SCARF)

(FINGERED AND ONSRUO JOINTED SPECIMENS)

(CONTROL SPECIMENS)

(FIgure 2.--Cutting diagram for specimens to be tested in compression parallel to the grain from Douglas-fir and white oak boards.)
Figure 4.--Details of the square-toothed scarf joint made by Gamble Brothers, Louisville, Kentucky. (Series 1 and 2)
Figure 5.—Details of the fingered joint made by Gamble Brothers, Louisville, Kentucky. (Series 1 and 2)
Figure 6.--Details of an Omsrud joint made by Gamble Brothers, Louisville, Kentucky. (Series 1 and 2)
Figure 7.--Details of control and plain scarf-jointed specimens to be tested in tension parallel to the grain -- Douglas-fir.
Figure 8.--Details of control and plain scarf-jointed specimens to be tested in tension parallel to the grain -- Douglas-fir and white oak.
Figure 9.—Cutting diagram for specimens from Douglas-fir boards to be tested for specific gravity and strength in tension and compression parallel to the grain.
Figure 10.—Details of a fingered joint made by Speedwall Division of Timber Structures Inc., Seattle, Washington. (Series 3)
Figure 11.—Details of specimens of Douglas-fir and white oak to be tested in tension parallel to the grain with serrated scarf, square-toothed scarf, fingered, and Onsrud joints.
NOTE: JOINTS WERE SYMMETRICALLY LOCATED WITHIN THE WIDTH OF A SPECIMEN

EXAMPLE OF A SQUARE TOOTHED SERRATED SCARF JOINT

SIDE VIEW

END VIEW

END JOINTED SPECIMEN

CONTROL SPECIMEN

SERIES 1, 2, AND 3

Figure 12.--Details of specimens of Douglas-fir and white oak to be tested in compression parallel to the grain with serrated scarf, square-toothed scarf, fingered, and Onsrud joints.

M 57419 $
Figure 13.--Cutting diagram for specimens from Douglas-fir boards to be tested in tension parallel to the grain.
SECTION NORMAL TO SLOPE OF SCARF

Figure 14.--Details of a serrated scarf joint made by Gamble Brothers, Louisville, Kentucky. (Series 5)
Figure 15.—Details of an oversul joint made by Gamble Brothers, Louisville, Kentucky. (Series 5)
Figure 16.—Machine set-up for tests in tension parallel to the grain, showing type of grips used for testing specimens with plain scarf joints and for those without joints.
Figure 17.—Machine set-up for tests in tension parallel to the grain, showing type of grip used for testing specimens with serrated, Onsrud, or fingered joints.
Figure 18.--Maximum strength in tension parallel to the grain as related to slope of plain scarf joint -- Douglas-fir (Series 1 and 4).

Note: Results of tests on Douglas-fir material from first and fourth series are shown to left and right of slope lines respectively.

Legend:
- **O**: Away
- **X**: At (in joint or where joint obviously contributed to failure)
- **Average**

*Z&M 67419 F*
Figure 19.--Maximum strength in tension parallel to the grain as related to slope of plain scarf joint -- white oak (Series 2).
Figure 20.--Maximum strength in tension parallel to the grain as related to slope of plain scarf joint -- Douglas-fir and white oak (Series 1, 2, and 4).
Figure 21.—Average maximum strength in tension parallel to the grain of specimens with scarf joints and ratios of strength values of specimens with and without scarf joints as related to specific gravity — Douglas-fir (Series 1 and 4).
Figure 22.—Average maximum strength in tension parallel to the grain of specimens with scarf joints and ratios of strength values of specimens with and without scarf joints as related to specific gravity -- white oak (Series 2).
Figure 23.—Maximum strength in tension parallel to the grain as related to specific gravity.
<table>
<thead>
<tr>
<th>TYPE OF JOINT</th>
<th>NUMBER OF JOINTED SPECIMENS</th>
<th>AVERAGE EFFICIENCY</th>
<th>SERIES NO.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SERRATED SCARF (FIGURE 3)</td>
<td>15</td>
<td>57%</td>
<td>1</td>
</tr>
<tr>
<td>SQUARE TOOTHED SCARF (FIGURE 4)</td>
<td>15</td>
<td>72%</td>
<td>1</td>
</tr>
<tr>
<td>SERRATED SCARF (FIGURE 14)</td>
<td>18</td>
<td>64%</td>
<td>5</td>
</tr>
<tr>
<td>FINGERED (FIGURE 5')</td>
<td>14</td>
<td>46%</td>
<td>1</td>
</tr>
<tr>
<td>ONSRUD (FIGURE 6')</td>
<td>15</td>
<td>25%</td>
<td>1</td>
</tr>
<tr>
<td>ONSRUD (FIGURE 15)</td>
<td>18</td>
<td>34%</td>
<td>5</td>
</tr>
<tr>
<td>FINGERED (FIGURE 10)</td>
<td>12</td>
<td>18%</td>
<td>3</td>
</tr>
</tbody>
</table>

**DOUGLAS-FIR**

<table>
<thead>
<tr>
<th>TYPE OF JOINT</th>
<th>NUMBER OF JOINTED SPECIMENS</th>
<th>AVERAGE EFFICIENCY</th>
<th>SERIES NO.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SERRATED SCARF (FIGURE 3)</td>
<td>14</td>
<td>53%</td>
<td>2</td>
</tr>
<tr>
<td>SQUARE TOOTHED SCARF (FIGURE 4)</td>
<td>13</td>
<td>55%</td>
<td>2</td>
</tr>
<tr>
<td>FINGERED (FIGURE 5')</td>
<td>15</td>
<td>43%</td>
<td>2</td>
</tr>
<tr>
<td>ONSRUD (FIGURE 6')</td>
<td>15</td>
<td>26%</td>
<td>2</td>
</tr>
</tbody>
</table>

**WHITE OAK**

Figure 24.—Strength in tension parallel to the grain of specimens with various end joints compared to corresponding controls.
<table>
<thead>
<tr>
<th>Type of Joint</th>
<th>Number of Jointed Specimens</th>
<th>Average Efficiency</th>
<th>Series No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serrated Scarf Joint (Figure 3)</td>
<td>15</td>
<td>100%</td>
<td>1</td>
</tr>
<tr>
<td>Square Toothed Scarf Joint (Figure 4)</td>
<td>15</td>
<td>97%</td>
<td>1</td>
</tr>
<tr>
<td>Onsrud Joint (Figure 6)</td>
<td>15</td>
<td>100%</td>
<td>1</td>
</tr>
<tr>
<td>Fingered Joint (Figure 5)</td>
<td>15</td>
<td>79%</td>
<td>1</td>
</tr>
<tr>
<td>Fingered Joint (Figure 10)</td>
<td>15</td>
<td>74%</td>
<td>3</td>
</tr>
</tbody>
</table>

**Douglas-Fir**

<table>
<thead>
<tr>
<th>Type of Joint</th>
<th>Number of Jointed Specimens</th>
<th>Average Efficiency</th>
<th>Series No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serrated Scarf Joint (Figure 3)</td>
<td>15</td>
<td>102%</td>
<td>2</td>
</tr>
<tr>
<td>Square Toothed Scarf Joint (Figure 4)</td>
<td>15</td>
<td>95%</td>
<td>2</td>
</tr>
<tr>
<td>Onsrud Joint (Figure 6)</td>
<td>15</td>
<td>100%</td>
<td>2</td>
</tr>
<tr>
<td>Fingered Joint (Figure 5)</td>
<td>15</td>
<td>99%</td>
<td>2</td>
</tr>
</tbody>
</table>

**White Oak**

Figure 25.—Strength in compression parallel to the grain of specimens with various end joints compared to corresponding controls.

2 N 67426 ©
Figure 26.—Typical failures of Douglas-fir specimens containing plain scarf joints tested in tension parallel to the grain: A, slope 1 to 3; B, slope 1 to 6; C, slope 1 to 10; D, slope 1 to 15; E, slope 1 to 20. (Series 1)
Figure 27.--Typical failures in tension parallel to the grain of Douglas-fir control specimens end matched to the plain scarf-jointed specimens. (Series 1)
Figure 28.—Typical failures in tension parallel to the grain of Douglas-fir specimens containing plain scarf joints: A, 1 to 20; B, 1 to 15; C, 1 to 12; D, 1 to 10; E, 1 to 6; F, 1 to 7. (Series 4)
Figure 29.--Typical failures in tension parallel to the grain of Douglas-fir specimens end matched to the plain scarf-jointed specimens. (Series 4)
Figure 30.—Typical failures in tension parallel to the grain of white oak specimens containing plain scarf joints: A, slope 1 to 3; B, slope 1 to 6; C, slope 1 to 10; D, slope 1 to 15; E, slope 1 to 20. (Series 2)
Figure 31.--Typical failures in tension parallel to the grain of white oak control specimens end matched to the plain scarf-jointed specimens. (Series 2)
Figure 32.—Typical failures in tension parallel to the grain of Douglas-fir specimens containing in group A serrated scarf joints as detailed in figure 3, in group B specimens 9 and 10 square-toothed scarf joints as detailed in figure 4, and specimens 153 and 155 of group B serrated scarfs as detailed in figure 14. (Series 1 and 5)
Figure 33.—Typical failures in tension parallel to the grain in Douglas-fir specimens containing in group A fingered joints as detailed in figure 5; in group B fingered joints as detailed in figure 10; and in group C Onsrud joints as detailed in figures 6 and 15. (Series 1, 3, and 5)
Figure 34.--Typical failures in tension parallel to the grain in white oak specimens containing in group A serrated scarf joints as detailed in figure 3, and in group B square-toothed scarf joints as detailed in figure 4. (Series 2)
Figure 35.--Typical failures in tension parallel to the grain in white oak specimens containing in Group A fingered joints as detailed in figure 5, and in group B Onsrud joints as detailed in figure 6.
(Series 2)
Figure 36.—Typical failures in compression parallel to the grain of Douglas-fir specimens containing various end joints: A, serrated scarf; B, square-toothed scarf; C, fingered; D, Onsrud; (Series 1). All made by Gamble Brothers, Louisville, Kentucky.
Figure 38.—Typical failures in compression parallel to the grain of white oak specimens containing various end joints: A, serrated scarf; B, square-toothed scarf; C, fingered; D, Onsrud. All made by Gamble Brothers, Louisville, Kentucky. (Series 2)
Luxford, Ronald Floyd
End joints of various types in Douglas-fir and white oak compared for strength, by
Madison, Wis., U. S. Forest Products Laboratory, 1961.
15 p., illus. (F.P.L. rpt. no. 1622)

End joints of various types were evaluated in tension and compression to determine strength ratios for various configurations.

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