THE INFLUENCE OF OVERLAP LENGTH ON ADHESIVE JOINT STRENGTH

Audrey G. Zink

Assistant Professor
Wood Science and Forest Products
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061-0323

Robert W. Davidson

Professor Emeritus
Wood Products Engineering
SUNY-CESF
Syracuse, NY 13210

and

Robert B. Hanna

Professor and Director
Wood Products Engineering
Center for Ultrastructure Studies
SUNY-CESF
Syracuse, NY 13210

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ABSTRACT

The influence of overlap length on the strength and failure mode of bonded wood double lap joints was investigated in this study. The overlap lengths ranged from 12.7 mm (0.5 in.) to 44.45 mm (1.75 in.) in 6.35-mm (¼-in.) increments. The side members were 50.8 mm (2 in.) long, and the center member was 88.9 mm (3.5 in.) long. All joint members were 25.4 mm × 25.4 mm (1 in. × 1 in.) in cross section. The type of wood was yellow-poplar (*Liriodendron tulipifera*), and the joints were loaded in double shear. The strength of the joint was found to increase slightly with increased overlap length. The failure mode of the joints shifted from cleavage of the side members for the shortest overlap lengths, to a combination of side splits and forward shear failures for the intermediate overlaps, to center splits for the longest overlap lengths studied. While the joint strength trends observed for the double lap wood joints were consistent with previous work on other materials and similar conditions, the failure modes with the wood adherends were different from any other studies to date.

Key words: Double lap joints, joint strength, adhesive connections, failure mode.

INTRODUCTION

Currently, there is no widely accepted design method for structural shear joints between wood and adhesives. Methods have been proposed by Krueger (1981) and Hoyle (1988) for nailed and elastomeric glued joints, but none has received wide treatment in design textbooks. Nevertheless, structural adhesive/wood connections frequently comprise many of the load-resisting components in structures and buildings such as arches, bridge decks, roof and floor trusses, and columns. An improved understanding of the complex mechanical behavior of structural shear joints with wood materials will help keep wood a competitive construction material, open up new applications for wood composites, and ensure the safety and integrity of entire structures.

Shear tests of double lap joints are one of the most commonly used methods for testing

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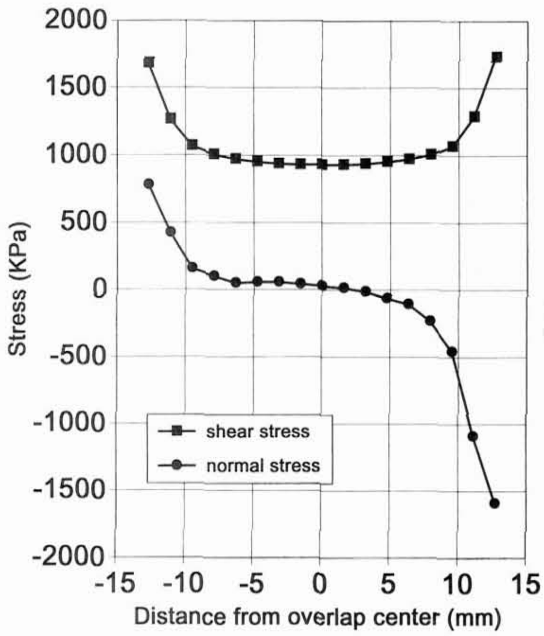

FIG. 1. Example normal and shear stress distribution along the overlap of a double lap joint.

structural adhesive connections. The samples are mechanically simple and often closely duplicate the geometry and service conditions for many wood/adhesive connections (Suddarth 1961; Goodman 1969; Selbo 1975; River and Gillespie 1978; Krueger 1981; Bullen 1986; Glos et al. 1988). There are limited experimental data on the influence of the geometric parameters such as overlap length on the strength and failure modes of double lap wood joints; and the existing analytical techniques are limited in their application to strength values and failure modes for double lap wood joints because they usually assume rigid adherends, a flexible adhesive, elastic behavior until failure, homogeneous material properties, adherends of similar materials, and center members twice the thickness of the side adherends. In addition, most models and analytical methods do not account for fracture, failure, bending of the side members, or members other than flat plates, and they usually assume that failure will occur in the adhesive.

Because of the lack of experimental data and applicable analytical studies on the strength and failure modes of double lap shear adhesive joints with wood adherends, the focus of this study was to determine the influence of overlap length on the joint strength and failure modes of double lap wood joints. Double lap joints were used to minimize the eccentric loading and bending of the side members that are introduced in single lap joints and to approximate actual glued joints for wood trusses and frames. Double lap shear tests also have the advantage that they eliminate the need for a jig to apply the shear force such as that described in ASTM Standard D905-49 (ASTM 1986a), which has been shown to alter the apparent strength of wood and adhesive joints (Norris 1957; McLeod et al. 1962; Hilbrand 1964; Okkonen and River 1988).

LITERATURE REVIEW

For ideal materials that are isotropic, elastic, and homogeneous loaded in tension or compression, it has been well established that the distribution of stress is not uniform along the overlap length because of the bending of the side members that is induced by the offset of the load and the reactions (Volkerson 1938; Goland and Reissner 1944; Mylonas and de Bruyne 1951; Cornell 1953; McLaren and MacInnes 1957; Renton and Vinson 1975; Delale and Erdogan 1981; Chen and Cheng 1983; Hart-Smith 1987; Gilibert et al. 1988; Adams 1989; Sancaktar 1991, among others). Figure 1 illustrates the shear and normal stress distribution as determined using the classical theory of elasticity solution of Goland and Reissner (1944) for a double lap shear joint constructed with idealized materials and loaded in compression. Even for ideal conditions, both shear and normal stresses exist due to the combination of axial stress, P/2A, and bending stress of the side adherends, MC/I. The magnitudes of these stresses are significantly greater at the beginning and end of the overlaps than anywhere else along the length.

These stress concentrations at the ends of the overlapped regions have been found to be highly dependent on the length of the overlapped region (Volkerson 1938; Goland and

Reissner 1944; de Bruyne and Houwink 1951; Renton and Vinson 1975; Adams et al. 1986; Glos et al. 1988; Adams 1989). Volkerson (1938) developed a series of curves that can be used to determine the influence of overlap length for double lap joints under tension or compression, if the joint is symmetrical on either side of the centerline, and if bending is prevented. The simplified stress concentration factor, Δ, that is the ratio of the maximum shear stress at the free ends of the overlap (τ_{max}) to the average shear stress on the joint (τ_{ave}) was determined to be

$$\Delta = \frac{Gl^2}{Esd} \tag{1}$$

where

G = shear modulus of the adhesive
d = thickness of the adhesive
s = thickness of one adherend strip
E = Young's modulus of the adherend
l = length of the overlap

and the average shear stress τ is given as

$$\tau_{ave} = P/bl \tag{2}$$

where

P = applied load
b = joint width
l = overlap length

For identical, rigid adherends and an adhesive of like material properties, Volkerson's analysis indicates that as the overlap length is increased, the ratio of maximum shear stress to average shear stress, Δ, increases exponentially. Because bending is prevented and the joint is symmetrical on either side of the centerline, the only stresses are shear stresses, and the increase in the ratio is due to the increase in the average stress in the joint and the corresponding decrease in the maximum stress at the free ends of the overlap with increasing overlap length. Goland and Reissner (1944) extended Volkerson's analysis to include bending of the side adherends. They define a dimensionless bending moment factor (K) that is the ratio of the magnitude of the moment at the edge of the joint to the value of the moment in a portion of the adherends away from the joint as follows:

$$K = \frac{2M_0}{Pt} \tag{3}$$

where

M_0 = magnitude of the edge moment
P = applied axial load
t = adherend thickness

It was found that the magnitudes of the moment were dependent upon the value of the applied axial load in the unjointed adherend, the joint dimensions, and the physical properties of the adherends. If the load on the joint is small, no bending takes place, K = 1.0, and the M_0 reduces to Pt/2. As the load is increased, the overlap rotates, bringing the line of action of the load closer to the centerline of the adherends, thereby reducing the value of the bending moment factor. For aluminum alloy adherends and an inflexible adhesive, it was found that as the overlap length increased, the moment factor, K, decreased; however, the maximum shear stresses increased.

Using double lap joints of Alclad sheet adherends (an aluminum alloy) and a Redux adhesive, de Bruyne (1967) determined that the joint strength (defined to be the failure load divided by the area of overlap) increased initially for increased overlap length and then leveled off once the yield strength of the aluminum was reached. Using laminated plate theory and the assumption of plane strain, Renton and Vinson (1975) determined that as the overlap length increases in single lap joints, the adhesive shear stress is reduced; however, beyond a certain overlap length, no significant reduction is possible. They also determined that a more uniform stress distribution occurs in the adhesive for increasing overlap length and for large overlap length-to-adherend thickness ratios (~10–12), failure will most likely occur in the adherend first, negating any advantage gained in increasing the overlap length. Their analysis is limited only to the adhesive and does not apply to the stresses in the adherends.

The strength and stress distribution of CFRP and steel double lap joints loaded in tension were analyzed experimentally and with an elastic-plastic model for a rubber-modified epoxy adhesive by Adams et al. (1986). In these joints, the CFRP composite was the center member, and the side members were high-tensile steel. The model included failure criteria based on a maximum plastic strain that the adhesive could withstand in shear and a limiting maximum principal tensile strain in the adhesive and the CFRP composite adherends. The design variables were the thickness of the adhesive layer, t_a, and the overlap length, L. As expected from previous studies (Kinloch and Young 1983), the predicted failure load for the basic double lap joint increased with increased overlap length followed by a plateau as the value of L increased. Shear failure of the adhesive in the composite/steel joints was suggested by the model as the failure mode; however, the experiments indicated that fracture between the lamina of the CFRP at the end of the overlap where the composite member joined the steel side members was the actual failure mode. This failure mode was caused by the transverse tensile stresses created in the joint by the internal bending moment being greater than the composite strength. The influence of varying the overlap length on the failure mode was not considered in this analysis.

The joint strength of rigid adherends and brittle epoxy adhesive double lap joints was observed by Adams (1989) to exhibit the trend of initial increase and then leveling off with increasing overlap length; however, a comparison of the experimental and linear and nonlinear analytical results indicated that the experimental values increased initially, leveled off, and then increased again with increasing overlap length, but the model simply indicated a flat plateau. Including a fracture mechanics component based on the assumption that the maximum shear strains in the joint can be estimated with an elastic analysis using a linear curve that described the shear strain energy to failure as the true tensile-stress curve in the analysis yields a better correlation between experimental values and predicted values for balanced double lap (Mallick and Adams 1987), single lap (Mallick and Adams 1989), and unbalanced CFRP/aluminum single lap joints (Adams and Mallick 1993). Both the predicted and experimental values of joint strength increased with an increase in the overlap length, with the best agreement being achieved for the joints constructed with the moderately strong but reasonably ductile epoxy adhesive.

The shear strength of glued double lap joints in timber structures is presented by Glos et al. (1988), where shear strength was defined to be the average shear stress along the glueline (the ultimate load at failure divided by the glued area of one side). The load-carrying capacity of joints with large overlap regions was experimentally determined using 376 full-size truss specimens. Of the many parameters investigated in this study, end distance, length of the glued area, and angle of gluing were found to be the decisive factors for shear strength of the structural wood joints. The end distance was an unbonded gap at the end of the bonded area of the center member, and the gluing angle was the angle between the grain directions of the glued members. The load-carrying capacity was greater for the joints constructed without a gap at the end of the glued area; and with increased angle of gluing, a steady reduction in joint strength was observed. When a gap was left at end of the center member, a steady reduction in shear strength with increased lap length was observed. In those without a tailing gap, the shear strength increased with increasing lap length for short overlaps (10–20 cm) and then decreased sharply as the overlap length exceeded 20 cm. As the lap length was increased through the range below 20 cm, the bending moment decreased, which resulted in a reduction in the influence of tensile stresses perpendicular to the grain; and above 20 cm, the reduction in shear strength was attributed to increased interaction of shear stress and stress perpendicular to the grain at the chord end.

From previous studies, the influence of overlap length, L, on the strength of lap shear joints can be summarized as follows: (a.) Volkerson's (1938) analytical study on double lap joints with no bending component indicates that as L increases, the ratio of maximum shear stress in the adhesive to the average shear stress in the adhesive increases. (b.) By including bending in the analysis, Goland and Reissner (1944) determined that as L increases, the bending moment on the side adherends is decreased and the maximum shear stress in the adhesive layer increases. (c.) DeBruyne (1967) determined experimentally that as L increases for single lap, rigid adherend joints, the joint strength (average shear stress) increases initially and then levels off. (d.) Renton and Vinson's theory of elasticity analysis (1975) of isotropic and anisotropic layered adherends indicates that as L increases, the adhesive shear stress decreases and a more uniform distribution of shear stress is predicted. (e.) Adams et al. (1986) and Adams (1989) determined experimentally and with finite element models including fracture mechanics parameters for CFRP composite adherends that as L increases, the predicted and observed failure load increases, as does the joint strength until an upper limit of L is reached, where the joint strength levels off. (f.) For full-size wood adherend truss members, Glos et al. (1988) determined that for increasing L, the joint strength initially increases, but then does not level off as with other materials, instead dropping sharply for the longest overlaps studied.

MATERIALS AND METHODS

Specimen preparation

All joint components were cut from a single board of yellow-poplar (*Liriodendron tulipifera*). Yellow-poplar was selected for experimental analysis because it glues very easily with a wide range of glues and under a wide range of gluing conditions (USDA Wood Handbook 1974), and it exhibits uniformity in anatomical structure (Panshin and de Zeeuw 1980). The average moisture content of the wood specimens prior to joint assembly was 9% as determined following ASTM Standard D-2016-83 Method A, Ovendry Method (ASTM 1986b). The average specific gravity at test was 0.35 as determined following ASTM Standard D-2395-83 Method D, Volume by Mercury Immersion Method (ASTM 1986c). Surfaces to be glued were knife-planed just prior to joint assembly, and the specimens were specific gravity matched. The adhesive was a room-temperature setting, liquid resorcinol-formaldehyde resin. The adhesive spread rate was 25 kg per 90 m^2 (50 lb of adhesive for 1,000 ft^2 of surface area). The adhesive was spread on the tangential surfaces of the blocks using open assembly times of 15 min and closed assembly times of 10 min. The pressure curing period was 24 h. Adequate pressure was applied to get squeeze-out of the adhesive from the gluelines, and pressure was adjusted approximately 30 min after initial application. A special jig was made to minimize shifting in the clamps and deviation from the desired overlap lengths. The joints were conditioned in a moisture chamber at 20°C (70°F) and 50% relative humidity for 6 days to complete the adhesive cure and bring the wood to the expected equilibrium moisture content obtained in the testing lab. The average moisture content of the joints at test was 9% as determined following ASTM Standard D-2016-83 Method A, Ovendry Method (ASTM 1986b).

The strength of structural adhesive joints with wood adherends varies with many factors other than joint geometry, including wood species, adhesive and wood surface preparation, bonding conditions, and testing methods. Care was taken to minimize the variability of strength caused by factors other than varying the overlap length in this study. The overlap lengths chosen for the joint strength and failure mode analysis were 12.7 mm, 19.05 mm, 25.4 mm, 31.75 mm, 38.1 mm, 44.45 mm (0.5 in., 0.75 in., 1.0 in., 1.25 in., 1.5 in., and 1.75 in.). This range represents approximately a one-tenth scale of the overlap lengths used in many mechanical and adhesive connections (for example, Glos et al. 1988). All joint members

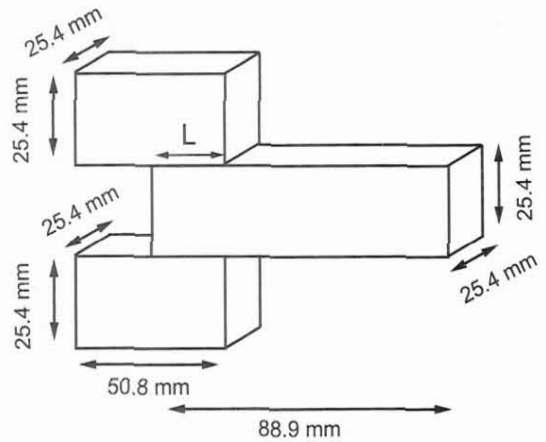

FIG. 2. Diagram of double lap joint.

were 25.4 mm × 25.4 mm (1 in. × 1 in.) in cross section. The depth of the joint members perpendicular to the gluelines was a unit depth (25.4 mm or 1 in.) because the results of analytical and empirical studies (de Bruyne and Houwink 1951; Glos et al. 1988, for example) have indicated that the depth of the joint members perpendicular to the gluelines has a negligible influence on the distribution of stress in the joints, and the distribution through the depth is uniform. Therefore, the 25.4-mm or 1-in. depth was chosen to represent unit depth slices through larger assemblies. Because the width has been found to influence the distribution of stress in the vicinity of the gluelines (de Bruyne and Houwink 1951; Lunsford 1961; Glos et al. 1988), a unit width was selected and held constant in all experimental specimens to provide a cross-sectional area of one unit (25.4 mm^2 or 1 $in.^2$). The side members were 50.8 mm (2 in.) long and the center member was 88.9 mm (3.5 in.) long. These lengths were chosen to ensure a uniform axial stress distribution in the center and side adherends so that the distribution in the vicinity of the glue joints would not be influenced by any localized concentrations at the ends of the adherends resulting from the applied load. In addition, the ratio of length to width for the center and side adherends was 3.5:1 and 2:1, respectively, which indicates that buckling of the short columns would not be expected (Bodig and Jayne 1982). Figure 2 illustrates the form and dimensions of the test specimen used.

Mechanical testing

A Baldwin-Emery SR-4 Universal testing machine was used to apply the compression load to the double lap specimens at a crosshead rate of 0.3048 mm (0.012 in.) per minute. The load data were recorded every 0.5 seconds. The joint strength was defined to be the load at failure divided by two times the bonded area of one side:

$$\tau = P_{max}/2A \qquad (4)$$

where

τ = joint strength
P = maximum load the joint carried
A = average of the two bonded areas

The strength defined in this manner is the average shear stress along the glueline. This is a commonly used definition for joint strength in adhesive lap joints. The apparent failure mode was recorded during testing when possible. After testing, the joints were examined using incident light microscopy of the fractured surfaces to determine an apparent failure mode following techniques established by Zink et al. (1994).

RESULTS AND DISCUSSION

Joint strength

Figure 3 is a plot of the joint strength versus the overlap length for the specimens tested in this study. The joint strength, as listed in Table 1, was calculated using Eq. 4 for each joint assembly, and the mean and standard deviation are plotted in Fig. 3. As illustrated in this figure, the strength of the double lap joint increases slightly with increasing overlap length but levels off as the overlap length is increased. While these results are in general agreement with the studies of isotropic and composite materials (de Bruyne 1967; Kinloch and Young 1983; Adams et al. 1986; Adams 1989) and the research on the load-carrying capacity of

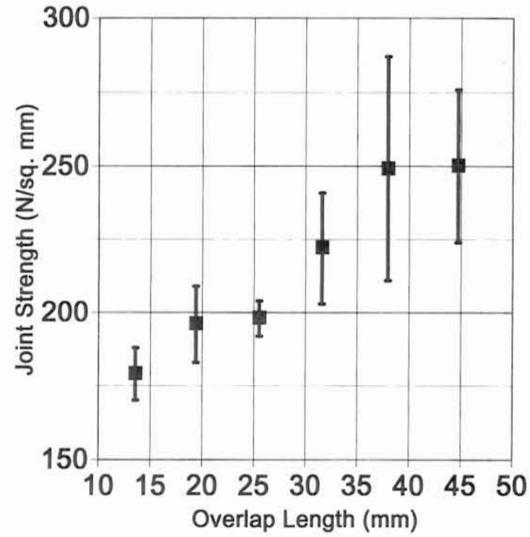

FIG. 3. The influence of increasing overlap length on the average shear strength of the double overlap wood joints.

TABLE 1. *Strength data from mechanical testing of double overlap joints.*

Test no.	Bond area (mm^2)	Ult. load (N)	Joint strength (N/mm^2)
A1	12.7	4,388	173
A2	14.2	4,725	166
A3	14.3	5,400	189
A4	13.2	4,941	187
A5	13.4	4,833	180
B1	19.1	6,885	181
B2	19.4	7,200	186
B3	19.3	8,235	213
B4	19.1	7,659	201
B5	19.5	7,857	201
C1	25.0	9,540	191
C2	25.3	10,080	199
C3	25.6	9,900	193
C4	25.9	10,355	200
C5	26.1	10,692	205
D1	30.4	1,780	210
D2	31.8	13,365	210
D3	32.1	13,914	217
D4	31.9	13,959	219
D5	31.6	16,110	255
E1	37.7	16,290	216
E2	38.0	17,640	232
E3	37.9	16,763	221
E4	37.9	23,400	308
E5	37.7	20,160	267
F1	44.6	23,400	262
F2	44.4	25,470	287
F3	44.9	21,960	245
F4	44.8	19,260	215
F5	44.6	21,690	243

full-size timber joints by Glos et al. (1988) for the shorter overlaps studied in their series, the sharp drop in joint strength observed by Glos et al. (1988) was not observed in this study. Glos et al. (1988) indicated that it was the tensile strength perpendicular to the grain that affected the failure in the shorter overlap range, and the reduction in joint strength for the longer overlaps is a result of increased interaction of shear stress and stress perpendicular to the grain. The sharp reduction in joint strength in Glos et al. (1988) and the leveling off observed in this and previous studies (de Bruyne and Houwink 1951; Kinloch and Young 1983; Adams et al. 1986; Adams 1989) is probably due to the same phenomenon of reduced bending stresses and increased shear stresses as the overlap length is increased, and eventually the joint strength reaches the yield limit of the adherends. As the overlap length is increased, the center member is embedded further into the joint, and the unsupported length of the side adherends is reduced. Analytical studies (Volkerson 1938; Goland and Reissner 1944; Adams 1989) have indicated that as the overlap length increases, the magnitude of the combined stresses changes: the bending factor decreases and the shear stress in the adhesive layer increases.

In addition to changing stress interactions, with the longer overlapping region of the joints examined in this study, the load is transmitted more fully and uniformly across the gluelines rather than simply at the very ends of the gluelines as expected with short overlaps (Renton and Vinson 1975); however, there is an upper limit to the increase in strength due to increased overlap. Because the concentration of stress is not as highly localized in the end regions and the reduction of the bending moment factor, K, with the longer overlap lengths, the full joint strength potential can be developed with the longer overlap lengths.

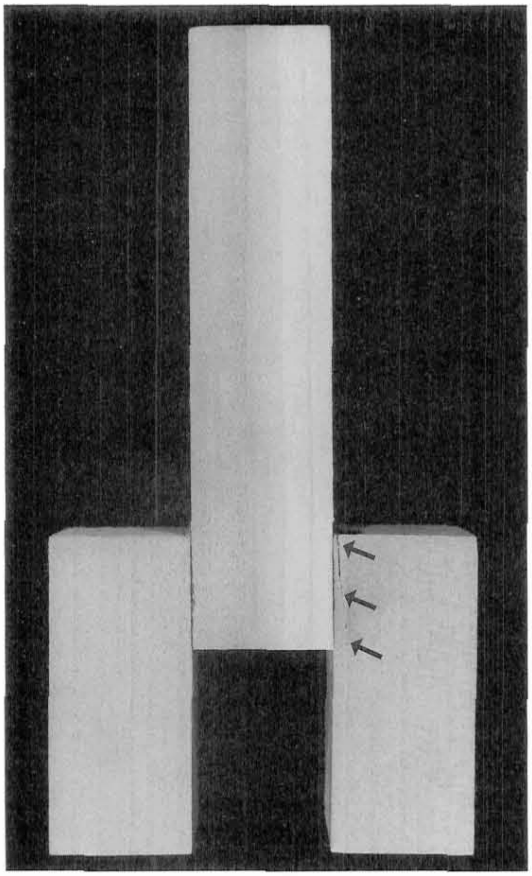

FIG. 4. Photograph of a typical failure due to side splitting or cleavage for a short overlap length of 19.05 mm (0.75 in.).

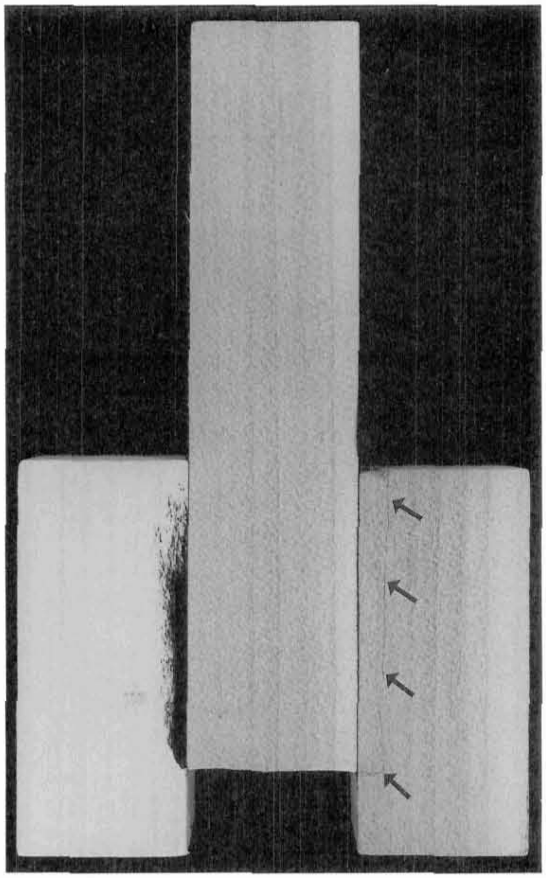

FIG. 5. Photograph of a failure due to forward shear of the side members for an overlap length of 38.1 mm (1.5 in.).

Failure mode

If an adhesive connection is subjected to an increasing load, it will eventually fail or cease to carry increased load. The failure of an adhesive connection may be in the adhesive, in the adherends, or in the interface between the adhesive and the adherends. If the failure is in the adhesive or adherend, the failure is considered cohesive. If the failure is in the interface, the failure is adhesive. With wood-to-wood joints bonded with a structural adhesive, failure almost always occurs in the wood and not in the adhesive, so that the highest stress and the failure of the wood members are of more interest than the highest stress or failure in the glue. Adhesive failure occurred in only two of the 50 joints tested, and these joints were removed from any subsequent analysis. The remainder of the failures were all cohesive failure within the wood adherends.

Three cohesive failure modes were identified during mechanical testing and subsequent microscopic studies of the failed joints: side splits, shear, and center splits. Side split failure is defined to be separation of either or both of the side adherends from the center adherend due to splitting of the wood near the gluelines. Figure 4 is an example of a typical side split in a short overlap specimen. Forward shear failure occurred when a portion of the side adherend slipped relative to the center adherend, as illustrated in Fig. 5. A center split was said to occur when the bonded end of the cen-

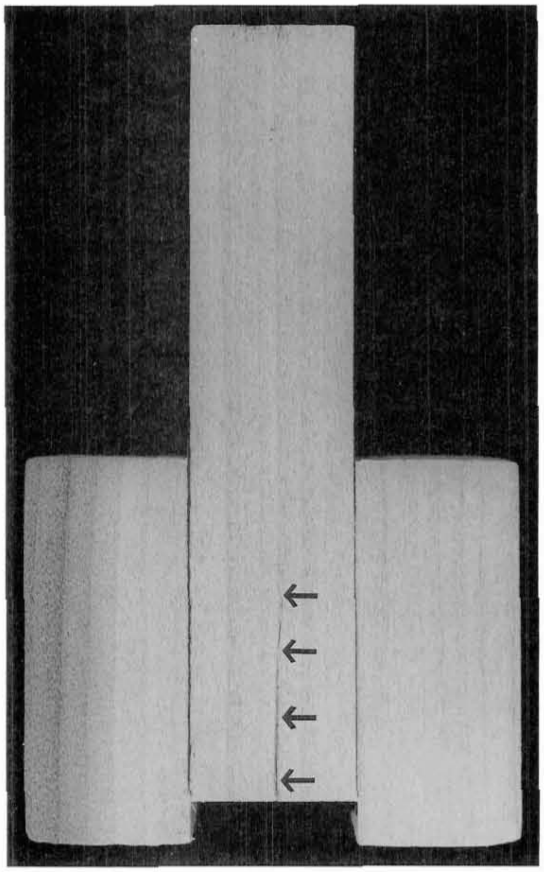

FIG. 6. Photograph of a typical failure due to center splitting in tension perpendicular to the grain for a long overlap length of 44.45 mm (1.75 in.).

TABLE 2. *Apparent failure mode.*

Test no.	Overlap length (mm)	Failure mode		
		Side split	Center split	Shear
A1	12.7	✓		
A2	14.2	✓		
A3	14.4	✓		
A4	13.3	✓		
A5	13.2	✓		
B1	19.3	✓		
B2	19.4	✓		
B3	19.5	✓		
B4	19.1	✓		
B5	19.6	✓		
C1	25.0	✓		✓
C2	25.5			✓
C3	25.6	✓		
C4	25.9	✓		
C5	25.5	✓		
D1	30.5	✓		
D2	31.8	✓		
D3	32.0	✓		
D4	31.8	✓		
D5	31.8	✓		
E1	37.8	✓		
E2	38.0		✓	✓
E3	38.2		✓	
E4	38.0		✓	
E5	37.7		✓	
F1	44.6		✓	
F2	44.4	✓		
F3	44.9		✓	✓
F4	45.0		✓	✓
F5	44.6		✓	

ter adherend split parallel to the gluelines. Figure 6 is an example of a typical center split in a longer overlap specimen. Table 2 is a summary of the visible failure mode of each of the specimens at each of the overlap parameters. Side split failures occurred most frequently in the shorter overlap lengths. The longer overlaps, 38.1 mm and 44.45 mm (1.5 in. and 1.75 in.), were characterized by center splits. Shear failures were infrequent and visible only on the surfaces of the intermediate and long overlaps.

Research on other composite materials (Renton and Vinson 1975; Adams 1989) has also recorded that failures within the composite might occur prior to failure of the glue bonds, depending on the thickness of the members and the composite structure. But unlike what Adams (1989) found, where the transverse tension failures were at the end of the joint closest to the load application (usually called leading end), the transverse tension failures in the wood lap joints in this study were at the tailing end of the joint. The deviation is probably due to the differences in composite structural arrangement and properties, tension loading by Adams, and the fact that the central members in the joint assemblies in this study were not twice the thickness of the side adherends as is often modeled with other joints.

Because the failures with the wooden lap shear specimens in this study were exclusively wood cohesive failures at all overlap lengths, it was not the adhesive connection that failed;

but it was the wood in the connection that failed in some combination of tension and shear failures due to the combined loading induced by axial loads and bending moments. This is not unusual with wood. In a review of fracture of wood, Patton-Mallory and Cramer (1987) indicate that mixed-mode failures often occur in many practical problems involving wood and wood composites. Williams and Birch (1976) also indicate that fracture of timber under combined tension and shear stresses is most often mixed-mode fracture. In mixed-mode fracture testing, they report that the forward shear component (mode II) appeared to have no effect, and failures occurred in cleavage or opening mode (mode I) due to splits in the wood from tension loading.

Due to the bending of the side adherends in the joints in this study, the side adherends tend to compress the center member at the leading end of the joint and peel or tear the tailing end of the joint. Because the tension perpendicular to the grain strength was so much lower than the shear and compression strength for the wood used in this study (USDA Wood Handbook 1974), the failures at all overlaps were due to a combination of shear stresses and transverse tension stresses. As the overlap lengths changed, the magnitude of the combined stresses changed, and the failure mode shifted. At the shorter overlaps, the stresses were predominately transverse tension stresses transferred at the ends of the overlaps due to the bending of the side adherends, and the failure mode was cleaving or peeling at the end of the joint. As the overlap length increased, the bending of the side members was decreased, the shear component of the combined loading became greater, and shear failures were observed in the specimens. At the longest overlaps, the load was most uniformly transferred across the joint thereby enlarging the area in which stresses perpendicular to the grain were being transferred and increasing the lever action in the central portion of the assembly. The stress concentrations were transferred to the central portion of the joint where the weakest component of the strength of the wood was exceeded, and, in all specimens examined, a central crack perpendicular to the grain developed.

SUMMARY AND CONCLUSIONS

The strength and failure modes were altered by the degree of overlap. For the scaled versions of full-size lap shear joints examined in this study, the strength of the joint increased initially with increased overlap length until a point when increased overlap did not result in an increase in the strength. As the overlap increased, the magnitude of the combined tension and shear stresses changed; and because wood is an orthotropic material with different mechanical properties in each of three directions, different strength components were exceeded as the combination of stresses shifted.

While the joint strength trends observed for the double lap wood joints were consistent with previous work on other materials and similar conditions, the failure modes with the wood adherends were different from any other studies to date. The failure mode for relatively short overlap lengths was predominantly due to splitting or cleavage in the wood side member in the vicinity of the tailing end of gluelines. The intermediate overlaps exhibited a combination of side splits and shear failures at the notches. The longer overlap length joints predominately failed from splits located in the central portion of the center member. The longer the overlapped regions, the more uniformity of load transfer into the central portion of the assembly, and the greater the chance of minimizing unexpected catastrophic failures due to cleavage of the side adherends as observed with the shorter overlap lengths. While the wood joints examined in this study qualitatively agreed with previous analysis and experiments, the failure modes were much different, and this must be kept in mind when designing lap shear joints with wood adherends.

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