GAP-FILLING ADHESIVES IN FINGER JOINTS

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ABSTRACT

By pretreating and heating mating surfaces, or the use of hot adhesive on untreated and unheated mating surfaces, Douglas-fir and southern pine finger joints were made comparable in tensile and bending strength with commercial finger joints of the same species even though the fingers were warped and loose fitting. Finger joints made with precured polyurethane hot-melt adhesive had sufficient strength for use in such applications as molding and window and door frames. Adhesives and techniques previously used to make high strength butt joints with eastern white pine failed to y;iedl comparable joints with Douglas-fir and southern pine.

GAP-FILLING ADHESIVES IN FINGER JOINTS

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INTRODUCTION

The wood industry has relied on end-joining lumber for many years. As the supply of high-quality timber decreased, and acceptance of large structural units such as laminated beams increased, manufacturers began to rely with increasing frequency on end-joining as a means of upgrading lumber and, subsequently, the product.

Most end-joining of lumber is done with finger joints. Other means are available. However, the simple butt joint has not developed high enough tensile strength to be accepted for structural components, while the scarf joint is difficult to make and wasteful of wood.

Strength requirements of finger joints depend on the end-use of the product. For example, the strength requirements of finger joints in outer laminations of structural beams are much greater than those in truck flooring, but truck flooring joints require greater strength than finger joints in molding.

There is no question that the wood industry can produce high-quality finger joints. However, in many cases human error, mechanical difficulties, or both, have led to the production of substandard finger joints. These joints often are not tight fitting, leaving adhesive-free gaps involving parts of fingers or whole fingers.

In a Forest Products Laboratory study, data showed that maximum joint strength of finger-joined wood is achieved with an adequately large glue-joint area and thin finger tips.[2] From a practical standpoint it is often uneconomical to cut thin fingers. This process requires sharp cutter heads and more than ordinary care and precision in cutting. This dilemma often leads to the production of shorter than desirable fingers, with square finger tips.

The fact that many commercial products have been made with loose-fitting and square-tipped fingers prompted us to investigate the use of gap-filling adhesives. We also employed bonding techniques previously reported which we felt would bond the end-grain of the square-tipped fingers.[3]

This study was conducted in two phases. In the first phase end-grain gluing techniques for butt joint bonding of species other than eastern white pine were evaluated. The second phase of the study consisted of using the techniques of the first phase and those employed in a previous study.[3] for bonding finger joints,

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

[2] Selbo, M. L. Effect of joint geometry on tensile strength of finger joints. Forest Prod. J. 13(9): 390-400. 1963.

[3] Schaeffer, R. E., and Gillespie, R. H. Improving end-to-end grain butt joint gluing of white pine. Forest Prod. J. 20(6): 39-42. 1970.

MATERIALS AND PROCEDURES

Butt Joints

Procedures for the preparation of adhesives, preparation and pretreating mating surfaces, heating of mating surfaces, and preparation and testing of specimen? were similar to those described previously.[3]

Adhesives.--(1) Unmodified epoxy adhesive. (2) Epoxy adhesive with 20 parts per hundred of resin (PHR) mercaptan terminated polysulfide flexibilizer. (3) Epoxy adhesive with 20 PHR dimerized C-18 fatty acid in its structure. (4) Adhesive (3) used at 150-175°F. All formulations consisted of a proprietary epoxy resin and diethylenetriamine (DETA) as a curing agent.

Mixing modified adhesives.--To 100 parts of epoxy resin, 20 parts of flexibilizer were added. The mixture was stirred until it was homogeneous. When the epoxy with C-18 fatty acid was used as the flexibilizer, the mixture was heated and stirred in a water bath at approximately 150' F. Before the addition of the curing agent, the mixture was permitted to return to room temperature (75-80° F.). Just before use, 11 parts of DETA were added. The adhesive mix was then stirred until it became homogeneous (but not for more than 5 min.) and used immediately. When this mixture was used hot, it was not permitted to return to room temperature before the curing agent was added.

Preparing hot epoxy adhesive.--The epoxy resin was heated on a hot plate to approximately 150-175° F. The manufacturer's recommended amount of curing agent (DETA) was added to the hot resin. The mixture was stirred immediately for approximately 15-30 seconds until it had a homogeneous appearance, and then poured onto unheated and untreated mating surfaces.

Wood.--Nominal 1-inch Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and southern pine (*Pinus* sp.) lumber was cut into blocks 4 inches wide and 14 inches long. The grain direction was parallel to the length of the block. The blocks were conditioned at 80° F. and 30 percent relative humidity. The average specific gravity based on volume at 6 percent moisture content and ovendry weight was 0.49 for Douglas-fir and 0.55 for southern pine.

Preparing surfaces for bonding.--The blocks were surfaced on one side and planed to uniform thickness (approximately 13/16 in.), and trimmed until their final dimension was 4 inches across the grain and 12 inches along the grain, With a sharp, hollow-ground saw, a cut was made across the grain equidistant from the ends of the 12-inch length. The two surfaces produced by this cut will be referred to as the mating surfaces.

Pretreating mating surfaces,--The mating surfaces were dipped in a 10 percent aqueous resorcinol solution for 5 seconds. They were permitted to air dry for 30 minutes and then dipped again for 5 seconds. After the second dipping, the mating surfaces were permitted to air dry for **4** hours.

Heating mating surfaces.--The mating surfaces were exposed to radiation 1 inch from an infrared lamp (250 watts) for 5 minutes. Surface temperatures were about 350° F. During this time the hardener was added to the previously prepared resin mixture. Immediately after the specimens were removed from the infrared radiation, the adhesive was spread on the hot mating surfaces.

Forming end-to-end-grain bonds.--A dam made of 1/16-inch veneer was glued around the edges of one of the mating surfaces to prevent the adhesive from running out of the joint before it gelled. The adhesive was spread on the mating surfaces with a spatula, except that the hot adhesive was applied by pouring. A shim 30 mils thick was placed at both ends of the adhesive spread area. The surfaces were joined under a pressure of about 1.3 pounds per square inch (p.s.i.) for 20 hours.

Preparing test specimens.--The joined blocks were conditioned for at least 2 weeks at 80° F. and 30 percent relative humidity. After conditioning, the excess adhesive and the dam were scraped from the blocks.

The bonded blocks were surfaced on one side, and then cut to a total length of 12 inches, with 6 inches of wood on each side of the center of the glueline. Five specimens for tension tests and two bending test specimens were cut from each bonded block.

Strips for tension tests were cut at 3/16-inch intervals through the thickness of the block and along the grain, and trimmed to 3/4-inch width on the unsurfaced side. These specimens were then cut to a total length of 9 inches, with 4-1/2 inches of wood on each side of the center of the glueline.

Bending test specimens were cut at 1/2-inch intervals through block thickness and along the grain, and trimmed to l/2-inch widths on the unsurfaced side,

Finger Joints

Adhesives.--Four gap-filling adhesives were evaluated in this phase of the study, including the three epoxy formulations used to make butt joints. The fourth adhesive was a precured polyurethane hot melt. A commercial water-base phenol-resorcinol resin was used to make standard finger joint controls. This adhesive was high-frequency (HF) cured.

Preparing adhesives.--Epoxy adhesives were prepared in the same manner as for forming butt joints. The phenol-resorcinol resin was mixed and used according to the manufacturer's recommendations for high-frequency curing. To evaluate the precured polyurethane, it was necessary to melt the adhesive on a hot plate and to dip the joint fingers in the molten adhesive.

Wood.--Douglas-fir, southern pine, and the heartwood of eastern whitepine (Pinus strobus L.) were used to make the finger joints. The average specific gravity for the three species based on volume at 6 percent moisture content and ovendry weight was 0.49 for Douglas-fir, 0.55 for southern pine, and 0.43 for the eastern white pine.

Preparing finger joints.--Blocks 4 inches wide and 14 inches long, with the grain direction parallel to the length were cut from nominal 8/4 lumber. The blocks were conditioned at 80°F. and 30 percent relative humidity. Fingers were cut with a sharp cutterhead at opposite ends of each block, with the cut made across the width of the block from edge to edge. The cut was parallel to the wide face. The blocks were cut in half and the machined ends matched for bonding. Finger configuration was: length, 1-1/2 inches; tip thickness, 1/32 inch; pitch, 10/32 inch.

The mating fingers were prepared for bonding by the same treatment with aqueous resorcinol solution, drying, and infrared heating used to form butt joints. During heating, the mating surface temperature rose to approximately 300°F. The mating pieces were placed on edge in a jig with side plates to maintain alinement and prevent adhesive loss. Adhesive was immediately poured into a 1/4-inch gap between the mating surfaces. The gaps were closed by hand pressure, extruding the adhesive throughout the area to be bonded. The gap at the end of the finger tips was maintained at approximately 1/16 to 1/8 inch. Assembly time was less than 5 minutes.

The fingers of joints made with hot epoxy adhesive were not pretreated or heated, but all other steps in the procedure were followed. Fingers for joints made with the precured polyurethane hot melt were not pretreated or heated, but were dipped in molten adhesive and joined by pressure in a carpenter's bench clamp.

Joints used for controls were made by spreading phenol-resorcinol adhesive on the fingers and then joining the mating surfaces under pressure in a HF curing machine according to recommendations of the adhesive manufacturer and accepted commercial practice for HF gluing.

Preparing test specimens. --Four bonded finger joints were made with each adhesive for each species. The bonded material was conditioned at least 7 days at 80° F. and 30 percent relative humidity. Five specimens 3/32 by 1-1/4 by 12 inches for tension tests and two specimens 1/2 inch in depth, 1-1/4 inches wide, and 12 inches long for bending tests were cut from each block. Saw cuts were made along the length of the bonded assembly.

Specimen testing

Tests were completed within 7 days after specimens were cut. The same test procedures were followed for both butt and finger joint specimens. Twenty specimens were tested in tension and eight specimens were evaluated in bending tests with each adhesive for each species. Moisture content at test was approximately 6 percent. Load-to-failure was measured with a universal testing machine. Bending specimens were subjected to third-point loading over a l0-1/2-inch span and with 3-1/2 inches between load points. The rate of vertical movement of the loading head for tension tests was 0.05 inch per minute; the rate for bending tests was 0.062 inch per minute.

RESULTS AND DISCUSSION

Butt Joints

Techniques and adhesives employed to bond eastern white pine end-to-end failed to yield butt joints with Douglas-fir or southern pine in which the full strength of the adhesive and adherend was realized (fig. 1). The type of break (in a plane near one of the interfaces), and the tensile strengths of the butt joints (approximately 4,000 p.s.i.) were similar to those for eastern white pine with untreated or unheated mating surfaces. Thus the techniques (pretreating and heating mating surfaces) employed in a previous study[3] to prevent undesirable molecular orientation during the cure of epoxy adhesives failed to yield high-strength butt joints for Douglas-fir and southern pine. This again indicates that end-grain surfaces are excellent substrates for the study of difficult-to-bond surfaces, but that the thinking which led to success in one case may be an over-simplification of the factors underlying successful bonding of wood end-grain-to-end-grain. This suggests further detailed and more fundamental study from both a physical and chemical approach,

The modulus of rupture of the Douglas-fir and southern pine butt-jointed specimens was approximately one-third that of the clear wood (fig. 2). This is not surprising, since adhesives usually perform rather poorly when resisting tensile peel or cleavage forces.

Failure to achieve high-strength butt joints with Douglas-fir and southern pine was not a deterrent in evaluating the gap-filling epoxy adhesives for bonding finger joints. While an adhesive may perform poorly when subjected to tensile peel or cleavage forces, it usually performs fairly well under load in shear. The adhesives in finger joints are stressed principally in shear while the joint itself is stressed in tension. We reasoned that if the same level of strength at the blunted end of finger tips could be achieved as that of the butt joints made from Douglas-fir and southern pine, the gap-filling epoxies would yield high-strength finger joints.

Finger Joints

Fingers of joints made with epoxy adhesives were often warped and loose fitting. This was caused by dipping the fingers in aqueous resorcinol solution and then air drying the fingers. Joints made with these fingers and gap-filling epoxy adhesives were approximately as strong in tension and bending as joints made of tight-fitting fingers

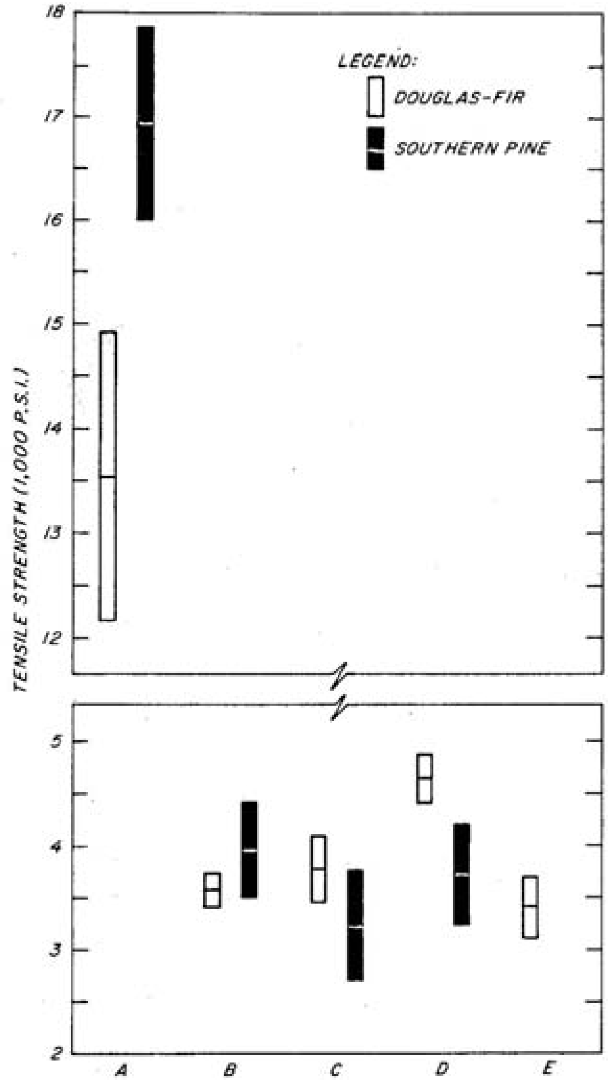

Figure 1.--Tensile strengths of non-jointed Douglas-fir and southern pine, and butt joints made with these species with epoxy adhesives. A, clear wood; B, unmodified epoxy adhesive; C, epoxy adhesive with 20 PHR polysulfide flexibilizer; D, an epoxy adhesive with 20PHR dimerized C-18 fatty acid in the epoxy resin structure; E, adhesive D used at 150°-175° F. All other adhesives were used at 80° F. Adhesive D was used on unheated and untreated mating surfaces. All other adhesives were used on heated and pretreated mating surfaces. All gluelines were 30 mils thick. Each bar represents the 95 percent confidence limits on the mean of a group of 20 specimens.

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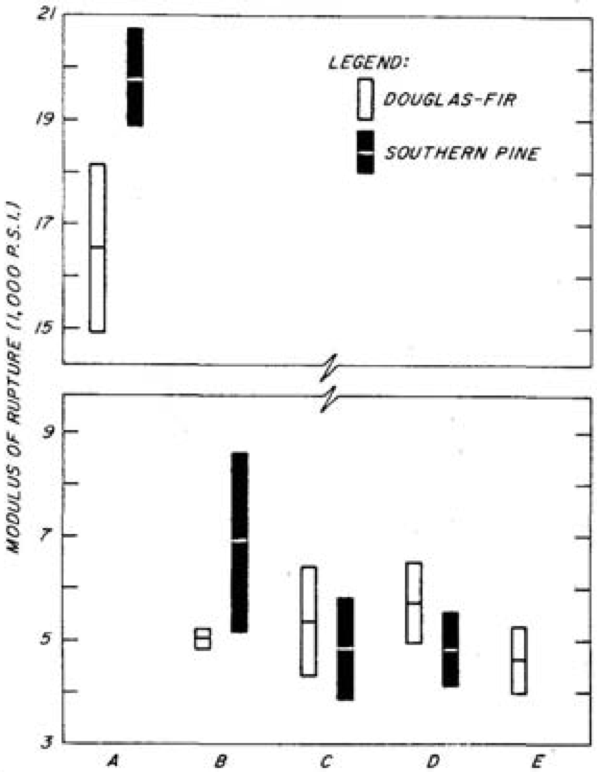

Figure 2.--Modulus of rupture of non-jointed Douglas-fir and southern pine, and butt joints made of these species with epoxy adhesives. A, clear wood; B, unmodified epoxy adhesive; C, an epoxy adhesive with 20 PHR polysulfide flexibilizer; D, an epoxy adhesive with 20PHR dimerized C-18 fatty acid in the epoxy-resin structure; E, adhesive D used at 150°-175° F. All other adhesives were used at 80° F. Adhesive D was used on unheated and untreated mating surfaces. All other adhesives were used on heated and pretreated mating surfaces. All gluelines were 30 mils thick. Each bar represents the 95 percent confidence limits on the mean of a group of eight specimens.

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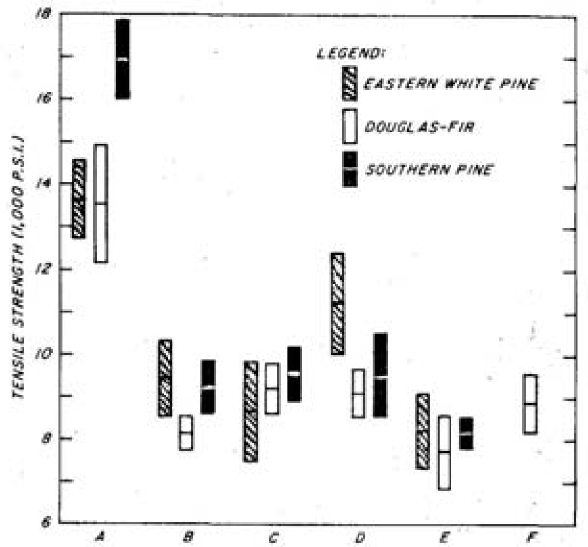

Figure 3.--Tensile strength of non-jointed eastern white pine, Douglas-fir, and southern pine, and finger joints made of these species. A, clear wood; B, joints made with unmodified epoxy adhesives; C, joints made with an epoxy adhesive containing 20 PHR polysulfide flexibilizer; D, joints made with an epoxy adhesive containing 20 PHR. dimerized C-18 fatty acid in the epoxy resin; E, joints made with an HF-cured phenol-resorcinol resin adhesive; F, joints made with hot (150°-175° F.) adhesive B. The hot adhesive was used on unheated and untreated mating surfaces. All other adhesives were used on heated and pretreated mating surfaces, at 80° F. Each bar represents the 95 percent confidence limits on the mean of a group of 20 specimens.

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bonded with HF-cured phenol-resorcinol-resin adhesive (figs. 3 and 4). Perhaps less precision in cutting and fitting of fingers can be tolerated, provided structural integrity of the joint is maintained by the use of suitable gap-filling adhesives.

Finger joints were approximately three times stronger in tension and bending than corresponding butt joints made with the same adhesive and species (fig. 5).

Tension and bending strength values were similar for finger joints made with hot (150°-175° F.) epoxy adhesive on untreated and unheated mating surfaces and joints made of pretreated and heated surfaces bonded with epoxy adhesive at 80° F. This is going in the right direction, as far as the economics of end joining with epoxy adhesives is concerned, by eliminating costly pretreatment and heating of surfaces. This result also gives impetus to the study of highly reactive, very fast curing (30 seconds or less) adhesive systems, and epoxy systems which require high temperatures (400° F.) to initiate cure.

Two classes of adhesives which have been

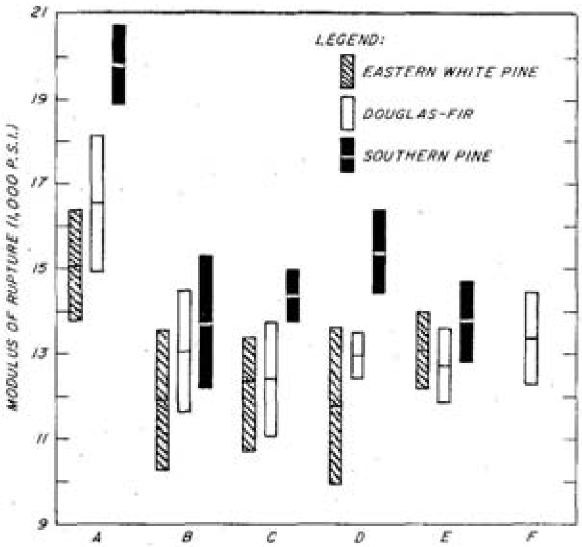

Figure 4.--Modulus of rupture of non-jointed eastern white pine, Douglas-fir, and southern pine, and finger joints made of these species. A, clear wood; B, joints made with unmodified epoxy adhesive; C, joints made with an epoxy adhesive containing 20 PHR polysulfide flexibilizer; D, joints made with an epoxy adhesive containing 20 PHR dimerized C-18 fatty acid in the epoxy resin; E, joints made with an HF-cured phenol-resortinol resin adhesive; F, joints made with hot (150°- 175° F.) adhesive B. The hot adhesive was used on unheated and untreated mating surfaces. All other adhesives were used on heated and pretreated mating surfaces, at 80° F. Each bar represents the 95 percent confidence limits on the mean of a group of eight specimens.

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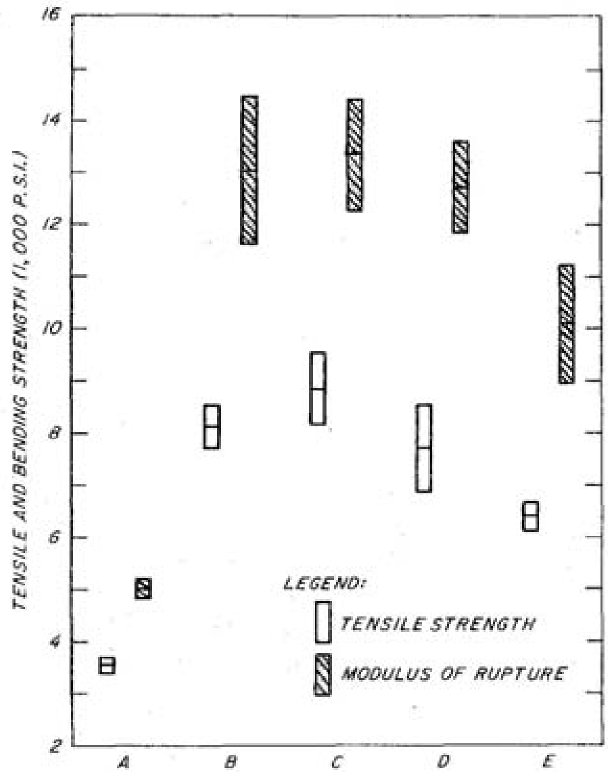

Figure 5.--Tensile strength and modulus of rupture for certain butt and finger joints made of Douglas-fir. A, butt joints made with unmodified epoxy adhesive; B, finger joints made with unmodified epoxy adhesive; C, finger joints made with unmodified epoxy adhesive heated to 150°-175° F; D, finger joints made with an HF-cured phenol-resorcinol resin adhesive; E, finger joints made with a precured polyurethane hot-melt adhesive. A and B mating surfaces were pretreated and heated. Al l other mating surfaces were untreated and unheated. Each bar represents the 95 percent confidence limits on the mean of a group of 20 tension specimens or eight bending specimens.

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receiving ever-increasing attention in the wood industry are the polyurethanes and hot melts. Polyurethanes are used as highly reactive two-part adhesive systems, or as precured hot melts. We selected a commercial precured polyurethane hot melt with 500 percent elongation and free film tensile strength of 11,300 p.s.i. The finger joints made with this adhesive were significantly lower in tensile and bending strength than similar joints made with epoxy adhesives (fig. 5). However, the tensile strength (6,400 p.s.i.) and modulus of rupture (10,100 p.s.i.) were at least twice those of the butt joints made with epoxy adhesive. This level of strength in end joints should be adequate for many applications, such as molding and window and door frames.

Most of the finger joints made with the epoxy- and phenol-resorcinol adhesives had tensile and bending strengths which compare favorably with those of some commercial finger joints made with melamine - urea and phenol - resorcinol adhesives. [4]

[4] Bohannan, B., and Selbo, M. L. Evaluation of commercially made end joints in lumber by three test methods. U.S. Forest Serv. Res. Pap. FPL 41, Forest Prod. Lab., Madison, Wis. 1965.

CONCLUSIONS

(1) Epoxy adhesives and gluing techniques used to successfully bond eastern white pine end-to-end failed to yield butt joints with Douglas-fir and southern pine in which the full strength of the adhesive and adherend was realized.

(2) The modulus of rupture of Douglas-fir and southern pine butt jointed specimens was approximately one-third that of the clear wood.

(3) Douglas-fir and southern pine with warped and loose fitting fingers were bonded with epoxy adhesives employing techniques used for the butt joints. The finger joints made in this way were comparable in tensile and bending strength with some commercial finger joints made with phenol-resorcinol and melamine-urea adhesives.

(4) For some purposes, finger joints of acceptable strength in tension and bending may be made from loose-fitting stock, provided a suitable gap-filling adhesive is employed in the bonding process.

(5) Finger joints made with a precured polyurethane hot-melt adhesive had a tensile strength of 6,400 p.s.i. and modulus of rupture of 10,100 p.s.i. which is probably sufficient for making molding and window and door frames.

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