# CREOSOTE TREATMENT EFFECT ON HARDWOOD GLULAM BEAM PROPERTIES[1]

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ABSTRACT

Flexure tests were conducted to determine the effect of creosote treatment on the performance of Combination A northern red oak, yellow poplar, and red maple glued-laminated (glulam) beams. This testing was conducted in accordance with ASTM D198-84 (ASTM 1987a), and the beams were

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fabricated in accordance with AITC 119-85 (AITC 1986), ANSI/AITC 190.1-83 (AITC 1983b), and AITC 200-83 (AITC 1983a). Shear tests were also conducted on samples taken from the beams to determine the glueline shear strength and percent wood failure (WF).

There was no significant difference ($P < 0.05$) between the modulus of rupture (MOR) of creosote-treated and untreated northern red oak beams. However, the MORs of the creosote-treated red maple and yellow poplar beams were significantly ($P < 0.05$) higher than those for untreated beams. There was no significant difference ($P < 0.05$) between the treated and untreated apparent modulus of elasticity (MOE) of each species. Therefore, the post-fabrication creosote treatment process from 145.92 to 215.76 kg/m$^3$ (9.11 to 13.47 pcf) average weight retention did not adversely affect the strength (MOR) or stiffness (MOE) of northern red oak, red maple, and yellow poplar Combination A glulam beams.

Glueline shear strengths for treated and untreated specimens of each species met or exceeded minimum performance criteria in AITC 200-83. Creosote treatment significantly ($P < 0.05$) increased glueline shear strength of red maple, but had no effect on the shear strength of red oak and yellow poplar specimens. Mean percentage wood failure of treated shear specimens was significantly ($P < 0.05$) greater than of untreated specimens in each species. Mean percentage wood failures of red oak and yellow poplar gluelines exceeded AITC 200-83 performance criteria; percentage wood failure of untreated (48%) and treated (59%) red maple shear specimens did not meet AITC 200-83 performance criteria.

*Keywords:* Creosote treatment, hardwood, glulam beams, flexural strength, glueline shear strength, percent wood failure, preservative.

## INTRODUCTION

Since its introduction into the United States in the 1930s, glued-laminated timber (glulam) has gained wide acceptance and is extensively used in many different applications by the construction industry. Technological advances and research in the areas of adhesives and treatment processes have increased the acceptance of glulam as a valuable and viable construction material for both interior and exterior applications. Because of the recent interest in modern timber bridges, enthusiasm has also grown for the development of viable and competitive hardwood glulam products. This is especially true in the northeastern states, where a harsh environment adversely affects concrete and steel bridges and where the saw-timber volumes of hardwood have steadily increased since 1955 (Waddell et al. 1989).

A number of studies were conducted to determine the effects of preservatives on hardwoods, particularly on gluelines for laminated beams (Selbo 1967, 1975; Koch 1985; Kilmer 1992). However, limited information is available on the effects of creosote on hardwood glulam beam strength properties. According to Koch (1985), oil-type preservatives usually result in no appreciable reductions in mechanical properties after treatment, since these preservatives apparently do not react with wood chemical constituents. Most recently Kimmel et al. (1994) reported on the characteristics of creosote-treated laminated veneer lumber (LVL) materials and found both red maple and yellow poplar LVL flexural and shear strength properties, in most cases, to be comparable to control specimens. No appreciable reductions in mechanical properties should occur due to normal creosote treatment; however, adverse or severe processing conditions during treatment, such as lengthy treatment time or high temperatures or both, may result in reductions in mechanical properties (Winandy 1988; Barnes and Winandy 1986). Since creosote-treated hardwood glulam members were being considered for exterior structural applications such as timber bridges and since treatment levels are high and processes are relatively severe, additional information is needed to determine the effects of preservative treatment on the strength values of hardwood glulam beams.

Research is currently underway in the Agricultural and Biological Engineering Department and the School of Forest Resources at the Pennsylvania State University to develop designs and specifications for hardwood glulam bridge systems. Research engineers and wood scientists have targeted three hardwood

TABLE 1. *Summary of hardwood glulam experimental plan.*

| Species | Combination[a] | Treatment[b] | Sample size |
|---|---|---|---|
| Northern Red Oak | A | None | 20 |
| | A | 145.92 kg/m$^3$ (9.11 pcf) | 20 |
| Yellow Poplar | A | None | 20 |
| | A | 215 kg/m$^3$ (13.47 pcf) | 20 |
| Red Maple | A | None | 20 |
| | A | 206.63 kg/m$^3$ (12.90 pcf) | 20 |

[a] AITC Hardwood Lamination combination.
[b] Average weight retention level of creosote preservative.

species (based on availability, gluability, treatability, and estimated structural performance) to be used in the development of these bridge standards: northern red oak (*Quercus rubra* L.); yellow poplar (*Liriodendron tuliperifera* L.); and red maple (*Acer rubrum* L.). One of the main objectives of this project was to ascertain whether a post-fabrication creosote treatment process adversely affected the strength and stiffness or the glueline shear properties of hardwood glulam beams.

This paper reports the results from testing 40 northern red oak, 40 yellow poplar, and 40 red maple glulam beams, 20 creosote-treated and 20 untreated of each species. A brief review of the fabrication process, treatment cycles, and test procedures used is included in this paper.

## STANDARDS AND CRITERIA

The American Institute of Timber Construction (AITC) operates a quality control and inspection program for the manufacture of glulam. This program is based on the American National Standard for wood products, ANSI/AITC A190.1, "Structural Glued Laminated Timber" (AITC 1983b) and the AITC 200-83 "Inspection Manual" (AITC 1983a). Although these standards are used mainly for the fabrication of softwood glulam, they are also applicable to hardwoods. AITC also publishes a "Standard Specification for Hardwood Glued Laminated Timber," AITC 119-85, (AITC 1986). The hardwood glulam test beams were fabricated in accordance with the manufacturing requirements in ANSI/AITC A190.1. Northern red oak, red maple, and yellow poplar beams were manufactured with visually graded lumber laminations in compliance with AITC 119-85 for Combination A glulam test specimens. All lumber for experimentation was mill-run material, with no efforts to control sapwood versus heartwood mixture.

All test and calculation procedures for flexural strengths and stiffnesses were completed in accordance with the American Society for Testing and Materials (ASTM) D198-84, "Standard Methods of Static Tests of Timbers in Structural Sizes" (ASTM 1987a). This standard is used to determine the allowable design values of most structural grades of lumber and engineered wood products. An apparatus was constructed to allow for the number of end-support degrees of freedom required by ASTM

TABLE 2. *Creosote treatment cycle for red oak test beams.*

| Stage | Level[a] | Time |
|---|---|---|
| Initial air pressure | 414 kPa (60 psig) | — |
| Fill cylinder under initial pressure | 414 kPa (60 psig) and 89 C (193 F) | 2 h 50 min |
| Pressure period | 1.31 MPa (190 psig) and 90 C (208 F) | 6 h |
| Pressure release and pump back solution | — | 0 h 30 min |
| Final vacuum period | 91 kPa (26.9 in Hg) | 2 h |
| Collect drips and release vacuum | — | — |

[a] All pressures are gauge pressures.

TABLE 3. *Creosote treatment cycle for red maple and yellow poplar test beams.*

| Stage | Level[a] | Time |
|---|---|---|
| Initial air pressure | 241 kPa (35 psig) | — |
| Fill cylinder under initial pressure | 241 kPa (35 psig) and 84 C (184 F) | — |
| Pressure period | 1.24 MPa (180 psig) and 90 C (194 F) | 4 h 30 min |
| Expansion bath period | | 8 h |
| Preservative back | — | 1 h |
| Vacuum period | 92 kPa (27.1 in Hg) | 2 h |
| Collect drips and release vacuum | — | — |

[a] All pressures are gauge pressures.

D198. Sample sizes were determined and the data were analyzed in accordance with ASTM D2915-86, "Standard Practice for Evaluating Allowable Properties for Grades of Structural Lumber" (ASTM 1987b).

Glueline shear tests were conducted in accordance with AITC T107 (AITC 1983a). Shear strength and percent wood failure values were experimentally determined and compared to performance criteria set forth in the AITC Inspection Manual 200-83. The shear strength performance standard is 90% of a species' clear wood shear strength at 12% equilibrium moisture content: 11.0 MPa (1602 psi) for northern red oak; 11.5 MPa (1665 psi) for red maple; and 7.4 MPa (1071 psi) for yellow poplar (Wood Handbook 1987). Percent wood failure (% WF) performance must meet or exceed 60% WF for northern red oak and 80% WF for red maple and yellow poplar (AITC 1983a).

## PROCEDURES

### *Grading*

The provisions of ANSI/AITC A190.1-83 (AITC 1983b) require that the grade combinations for structural hardwood glulams shall be as provided in the current edition of AITC 119-85 (AITC 1986). In addition, hardwood lumber used in laminating timbers shall be visually graded to meet the knot size and slope of grain requirements, along with other supplemental requirements, as set forth in AITC 119-85. AITC 119-85 designates hardwood glulam combinations by the letters A, B, C, D, and E, each of which represents a different grade of lamination stock based on knot size and slope of grain. All of the beams in this study were fabricated as Combination A hardwood glulams. Consequently, lumber for beam fabrication was restricted to a maximum knot to dressed beam width ratio of 0.10. In addition, the laminations in the outer 10% of each beam cross section had slope of grain less than 1:16, whereas the core laminations had a slope of grain less than 1:8. A piece of lumber with a knot/width ratio less than or equal to 0.1, and a slope of grain less than or equal to 1:16 was designated "AO" (Combination A, Outer lamination); a piece of lumber with a knot/width ratio of 0.1 and a slope of grain greater than 1:16 but less than or equal to 1:8 was desig-

TABLE 4. *Loading cases and nominal dimensions.*

| Species | Dimensions b × d × L mm (in. × in. × ft.) | Span length, s mm (ft) | Span-to-depth ratio (s/d) |
|---|---|---|---|
| Northern Red Oak | 100 × 230 × 4,115<br>(4 × 9 × 13.5) | 3,660<br>(12.0) | 17.7 |
| Yellow Poplar | 79 × 222 × 4,115<br>(3 × 8.75 × 13.5) | 3,660<br>(12.0) | 17.1 |
| Red Maple | 79 × 222 × 4,115<br>(3 × 8.75 × 13.5) | 3,660<br>(12.0) | 17.1 |

nated "AC" (Combination A, Core lamination).

*Number of specimens and layup design*

The glulam test specimens were fabricated in accordance with AITC 200-83 (AITC 1983a) using finger joint details as specified by ANSI/AITC A190.1-83 (AITC 1983b). End joints were glued with a radio frequency cured melamine resin; faces were bonded with Indspec resorcinol-formaldehyde resin. Open assembly time was approximately 20 min; clamping pressures were between 550 to 689 kPa (80 to 100 psi).

One hundred and twenty test beams were fabricated at a commercial laminating plant, 40 beams each of northern red oak, red maple, and yellow poplar. Test beams had nine 25-mm (1-in.)-thick laminations. Twenty of the 40 beams in each species (60 total) were creosote-treated to the average weight retentions listed in Table 1. Before treatment, weights and physical measurement (length, width, etc.) were recorded, and each test beam was identified using an aluminum tag. These test samples were treated in a commercial charge of mixed hardwood crossties using preservative solution meeting the American Wood-Preservers' Association (AWPA) P2 specifications for coal tar creosote solution. The treatment cycle for the red oak beams is summarized in Table 2. The treating cycle was adjusted for the red maple and yellow poplar beams to increase the weight retention of creosote. The revised treating cycle for the red maple and yellow poplar beams is summarized in Table 3.

The size of all test specimens met the slenderness ratio (l/d) and lateral stability requirements as set forth in ASTM D198-84 (ASTM 1987a). The northern red oak beams were nominally 100 × 230 mm (4 × 9 in.) by 4,115 mm (13.5 ft) long. The yellow poplar and the red maple beams were 79 × 222 mm (3 × 8.75 in.) by 4,115 mm (13.5 ft) long (Table 4). Since all beams were less than 254 mm (10 in.) in depth, only one AO lamination in the bottom and top of the cross section was required to meet the layup design requirements of AITC 119-85 (AITC 1986) for Combination A glulam beams (Fig. 1).

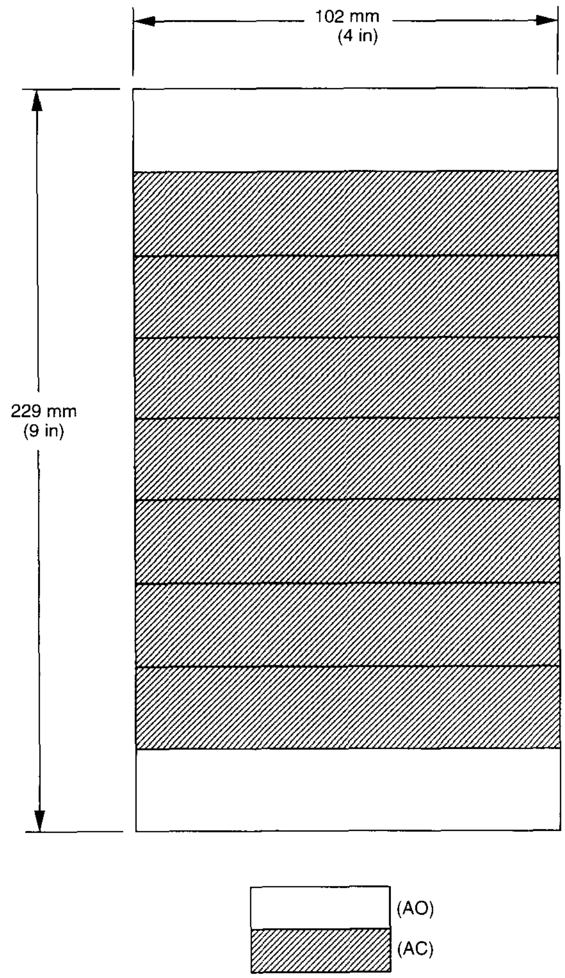


FIG. 1. Layup design for Combination A hardwood glulam.

*Standard flexure tests*

Flexural tests were conducted to failure in accordance with Sections 4 through 11 of ASTM D198-84 (ASTM 1987a). An Ametek universal testing machine with a 267 kN, ±0.267 kN (60,000 lb, ±60 lb), capacity was used to apply the load to the spreader bar of a third point loading apparatus. All deformation rates were within a range of 5 and 8 mm/min (0.2 and 0.3 in./min). A deflection

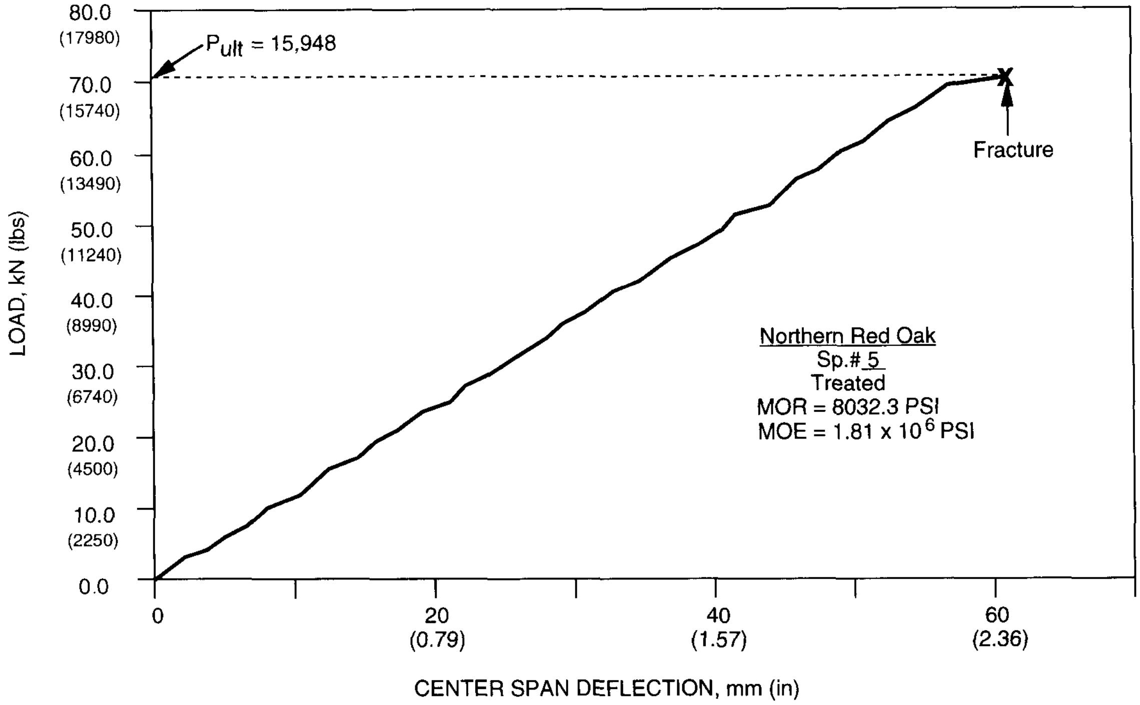


FIG. 2. Typical load vs. deflection curve.

yoke system equipped with transducers was utilized to measure the neutral axis deflection relative to the reactions. The deflections were measured using three linear variable displacement transducers (LVDTs) (accurate to $\pm 0.25$ mm [0.01 in.]) and were placed in the shear free zone. Load and deflection data were collected with a Zenith personal computer data acquisition system; measurements were recorded every 5 sec.

Measured deflections and their associated loads recorded during the full-size flexure tests were used to develop a load versus deflection curve, similar to the one shown in Fig. 2, for each specimen. From this curve and elastic beam theory, the apparent modulus of elasticity (MOE) and the ultimate modulus of rupture (MOR) were calculated.

### *Glueline shear tests*

One of the ends of each beam was removed after the flexure test to provide shear specimens following AITC T107 (AITC 1983a) procedures. The standard "stair-step" shear specimen was prepared from each beam end (Fig. 3). Destructive testing to evaluate shear strength was accomplished using a Tinius-Olsen universal testing machine equipped with an ASTM D905 glueline shear tool. Length and width dimensions for individual gluelines were recorded to determine actual test shear area. Load at failure was also recorded for subsequent computation of shear strength. After each individual glueline was tested to failure, the corresponding laminations were separated and evaluated for percent wood failure.

## RESULTS

Table 5 summarizes the mean MOR and apparent MOE along with the corresponding standard deviation and coefficient of variation (COV) for each species and treatment. Cumulative distributions of MOR and MOE for the treated and untreated samples of each species are presented in Figs. 4 and 5, respectively. The lower fifth percentile moduli of rupture at 75% tolerance limit ($MOR_{0.05}$) are also presented in Table 5 for the treated and untreated

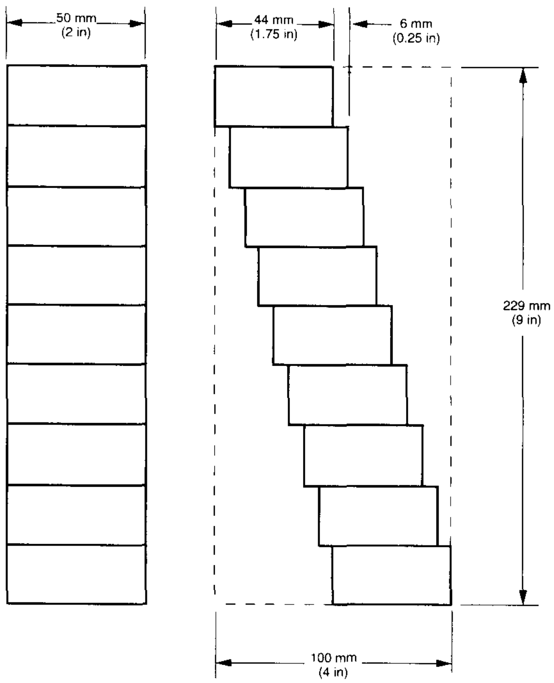


FIG. 3. Typical shear specimen.

samples of each species. The COVs for MOR are higher than for MOE for both the creosote-treated and untreated samples for each species tested. This characteristic is expected since there is higher variability in the mode of ultimate failure (due mainly to edge knots, slope of grain, and finger joints) than in the behavior through the elastic range of the beams.

Table 6 summarizes the mean shear strength and percent wood failure results along with the corresponding standard deviations for each species/treatment combination. Shear strength values exceeded required performance levels for each species regardless of treatment. Percent wood failure results for red oak and yellow poplar also met or exceeded AITC performance criteria. Percent wood failure results for red maple did not meet required performance level.

## ANALYSIS AND DISCUSSION

An analysis of variance (ANOVA) was conducted to test the hypothesis that the creosote

TABLE 5. *Summary of glulam flexural test results.*

| | | | Treated | Untreated |
|---|---|---|---|---|
| Northern Red Oak | MOR MPa (psi) | Mean | 71.1 (10,310) | 68.1 (9,870) |
| | | SD | 9.0 (1.309) | 10.0 (1,456) |
| | | COV | 12.7% | 14.8% |
| | | $MOR_{0.05}$[b] | 53.6 (7,780) | 48.6 (7,050) |
| | MOE[a] GPa (psi) | Mean | 12.7 (1,840,000) | 13.0 (1,880,000) |
| | | SD | 0.6 (91,300) | 0.7 (108,400) |
| | | COV | 4.9% | 5.7% |
| Yellow Poplar | MOR MPa (psi) | Mean | 56.5 (8,200) | 47.6 (6,900) |
| | | SD | 12.2 (1,767) | 8.2 (1,195) |
| | | COV | 21.5% | 17.3% |
| | | $MOR_{0.05}$[b] | 33.0 (4,790) | 31.6 (4,590) |
| | MOE GPa (psi) | Mean | 12.4 (1,800,000) | 12.3 (1,790,000) |
| | | SD | 0.6 (89,700) | 0.7 (108,600) |
| | | COV | 5.0% | 6.1% |
| Red Maple | MOR MPa (psi) | Mean | 64.4 (9,340) | 55.7 (8,080) |
| | | SD | 13.5 (1,959) | 12.7 (1,847) |
| | | COV | 21.0% | 22.9% |
| | | $MOR_{0.05}$[b] | 38.3 (5,560) | 31.2 (4,520) |
| | MOE GPa (psi) | Mean | 13.3 (1,930,000) | 13.0 (1,890,000) |
| | | SD | 0.8 (109,400) | 0.5 (79,100) |
| | | COV | 5.7% | 4.2% |

[a] Apparent MOE.
[b] Lower fifth percentile exclusion limit at 75% tolerance (ASTM 1987b).

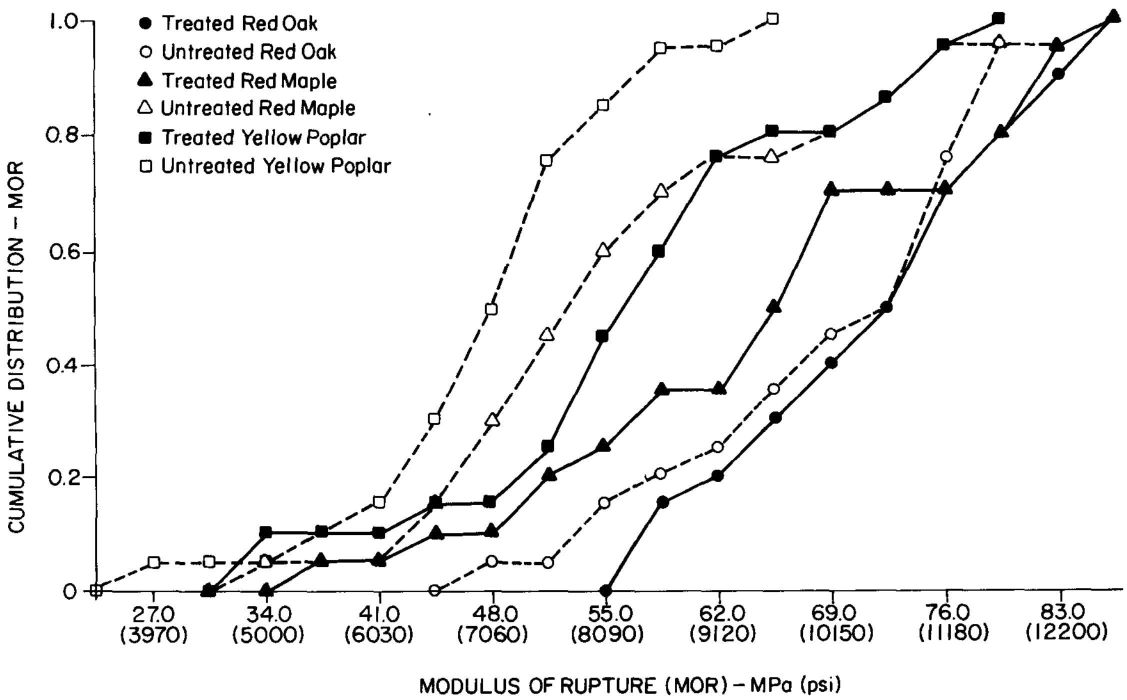


FIG. 4. Cumulative distributions of modulus of rupture for treated and untreated red oak, red maple, and yellow poplar Combination A glulam beams.

treatments did not adversely affect the MOR, MOE, glueline shear strength, and % WF of northern red oak, yellow poplar, and red maple glulam beams. Table 7 summarizes the results of the ANOVA for the flexure tests (MOR and MOE) and the glueline shear tests (shear stress and % WF). Although there was no significant difference ($P < 0.05$) between the treated and untreated MOR of the northern red oak glulam beams (71.1 MPa [10,308 psi] vs. 68.0 MPa [9,866 psi]), there was a significant difference ($P < 0.05$) between the MOR of the treated and the untreated yellow poplar (56.5 MPa [8,200 psi] vs. 46.2 MPa [6,689 psi]) and red maple (64.4 MPa [9,344 psi] vs. 55.7 MPa [8,083 psi]) glulam beams. Despite the differences, the mean MOR of the treated glulam beams was always higher than the mean MOR of the untreated beams for every species (Table 5). Given this result, the inference can be made that the creosote treatment process did not adversely affect the strength of northern red oak, red maple, or yellow poplar glulam beams. The probable reason for the increase in MOR after treatment is the glueline exposure to elevated temperatures and pressures during creosoting shortly after beam fabrication. The $MOR_{0.05}$ of the treated beams exceeded the $MOR_{0.05}$ of the untreated beams for each species.

There is no significant difference ($P < 0.05$) between the MOE of treated and untreated beams for any species. The absolute difference between the mean MOE of the treated and untreated northern red oak, red maple, and yellow poplar beams was 0.28, 0.03, and 0.27 GPa ($4.0 \times 10^4$, $5.0 \times 10^3$, and $3.9 \times 10^4$ psi), respectively (Table 5).

Observations during testing revealed that most of the beams failed at finger joints, at knots, or at steep slope of grain. A very low percentage (<1%) of beams failed in pure tension or compression in zones free of visually observed strength-reducing characteristics. Since the ultimate flexure strength of the beams is influenced more by the localized wood strength-reducing characteristics than is the

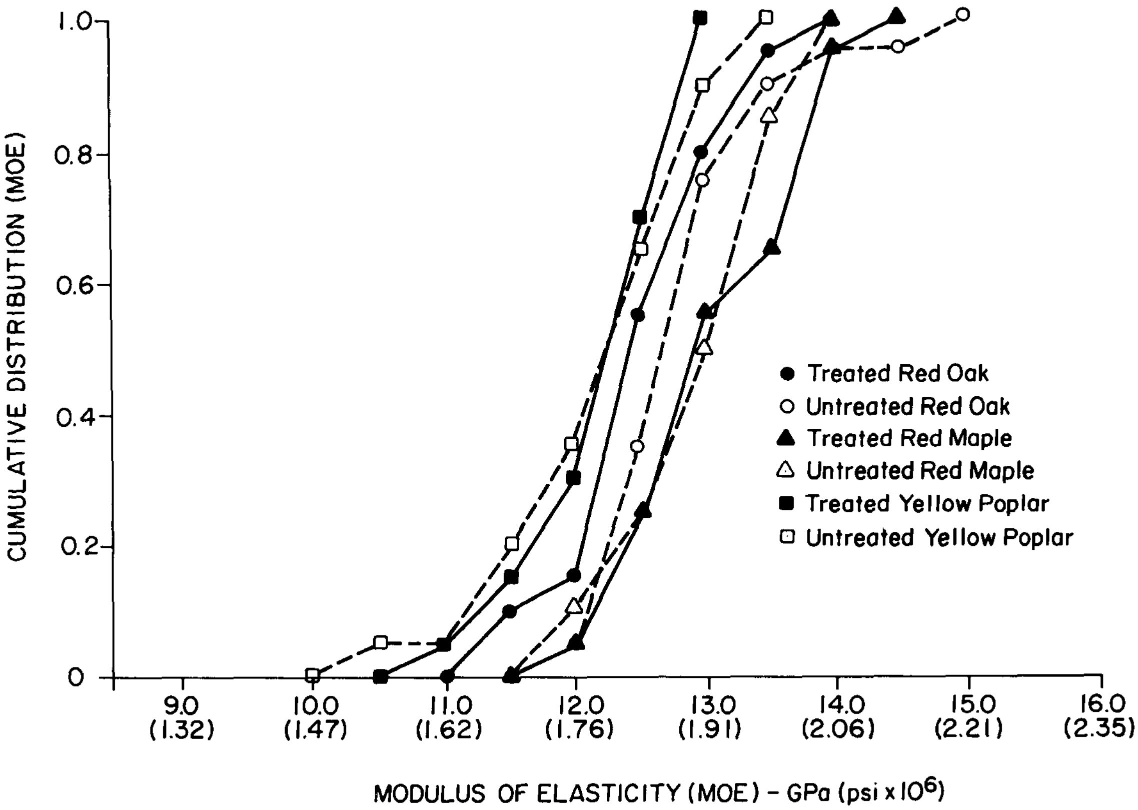


FIG. 5. Cumulative distributions of modulus of elasticity for treated and untreated red oak, red maple, and yellow poplar Combination A glulam beams.

stiffness, there is more variation in the MOR values than in the MOE values. Therefore, it may be more appropriate (for relatively small sample sizes) to use the MOE results to describe the difference in the performance of creosote-treated and untreated hardwood glulam beams.

There was no significant ($P < 0.05$) difference between treated and untreated means for the shear strength parameter for red oak or yellow poplar. However, the shear strength parameter of treated red maple was significantly ($P < 0.05$) different from the shear strength of untreated red maple. Mean % WF levels of the creosote-treated shear specimens were significantly ($P < 0.05$) different from those of untreated test specimens for all three species. Both the treated and untreated observed average glueline shear strength values for each species tested either met or exceeded the minimum performance criteria. This would indicate that post-treatment with creosote has no adverse effect on glueline shear strength for any species and adhesive used in this experiment. Mean % WF in shearlines exceeded performance criteria for treated and untreated red oak and yellow poplar. Mean % WF in both treated and untreated red maple gluelines did not meet standard performance criteria. This suggests that greater care should be exercised in specifying surface quality and clamping pressures when fabricating red maple glulam. Similar observations were noted by Manbeck et al. (1993).

## CONCLUSIONS

The conclusions drawn from this research are:

TABLE 6. *Summary of glueline shear tests.*

| | | | Treated | Untreated | Minimum performance criteria |
|---|---|---|---|---|---|
| Northern Red Oak | Shear stress MPa (psi) | Mean | 16.3 (2,365) | 15.8 (2,295) | |
| | | SD | 2.6 (376) | 3.6 (522) | 11.0 (1,602) |
| | | COV | 0.4% | 22.8% | |
| | Wood failure (%) | Mean | 89 | 80 | |
| | | SD | 18 | 26 | 60 |
| | | COV | 20.2% | 32.5% | |
| Yellow Poplar | Shear stress MPa (psi) | Mean | 12.5 (1,815) | 12.5 (1,815) | |
| | | SD | 0.8 (114) | 1.2 (173) | 7.4 (1,071) |
| | | COV | 6.3% | 9.5% | |
| | Wood failure (%) | Mean | 93 | 87 | |
| | | SD | 4 | 12 | 80 |
| | | COV | 4.3% | 13.8% | |
| Red Maple | Shear stress MPa (psi) | Mean | 15.2 (2,200) | 17.0 (2,460) | |
| | | SD | 2.1 (308) | 1.8 (268) | 11.5 (1,665) |
| | | COV | 14.0% | 10.9% | |
| | Wood failure (%) | Mean | 46 | 59 | |
| | | SD | 15 | 10 | 80 |
| | | COV | 32.6% | 16.9% | |

1. The post-fabrication creosote treatment process to 145.92, 206.63, and 215.76 kg/m$^3$ (9.11, 12.90, and 13.47 pcf) average weight retention, respectively, did not significantly ($P < 0.05$) affect the stiffness (MOE) of northern red oak, red maple, and yellow poplar glulam Combination A beams.
2. The post-fabrication creosote treatment process to 145.92 kg/m$^3$ (9.11 pcf) average weight retention did not significantly ($P < 0.05$) affect the strength (MOR) of northern red oak, glulam Combination A beams.
3. The post-fabrication creosote treatment process to 206.63 and 215.76 kg/m$^3$ (12.90 to 13.47 pcf) average weight retention, respectively, significantly ($P < 0.05$) affected the strength (MOR) of red maple and yellow poplar glulam Combination A beams.
4. The mean MOR of the treated red maple

TABLE 7. *Summary of ANOVA. Testing effects of creosote treatment.*

| Species | Property | Computed statistic | CI | Actual statistic | Difference |
|---|---|---|---|---|---|
| Northern Red Oak | MOR | $F = 4.17$ | 95% | $F = 1.02$ | No |
| | MOE | $F = 4.17$ | 95% | $F = 1.65$ | No |
| | Shear | $P = 0.05$ | 95% | $P = 0.0538$ | No |
| | % WF | $P = 0.05$ | 95% | $P = 0.0001$ | Yes |
| Yellow Poplar | MOR | $F = 4.17$ | 95% | $F = 7.49$ | Yes |
| | MOE | $F = 4.17$ | 95% | $F = 0.02$ | No |
| | Shear | $P = 0.05$ | 95% | $P = 0.933$ | No |
| | % WF | $P = 0.05$ | 95% | $P = 0.004$ | Yes |
| Red Maple | MOR | $F = 4.17$ | 95% | $F = 4.39$ | Yes |
| | MOE | $F = 4.17$ | 95% | $F = 1.63$ | No |
| | Shear | $P = 0.05$ | 95% | $P = 0.0001$ | Yes |
| | % WF | $P = 0.05$ | 95% | $P = 0.0097$ | Yes |

and yellow poplar beams was always higher than the mean MOR of untreated beams. Therefore, the post-fabrication creosote treatment process to 206.63 and 215.76 kg/m$^3$ (12.90 to 13.47 pcf) average weight retention, respectively, did not adversely affect the strength (MOR) of the red maple and yellow poplar Combination A glulam beams.

5. Post-treatment with creosote has no adverse effect on glueline bond quality for any species or adhesive used in this study. Therefore, structural engineers may confidently use the allowable strength and stiffness values published in AITC 119-85 (AITC 1986) or future editions for both untreated and creosote-treated (up to approximately 192 kg/m$^3$ (12 pcf)) for red oak, red maple, and yellow poplar glulam members.

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