Mechanical Performance of Nail-Laminated Posts Manufactured from Reclaimed Chromated Copper Arsenate–Treated Decking Lumber

John J. Janowiak
Robert H. Falk
Brad A. Gething
John A. Tsirigotis

Abstract

This study determined the mechanical properties of nail-laminated (nail-lam) posts manufactured from reclaimed chromated copper arsenate (CCA)–treated decking lumber. Though CCA-treated lumber is no longer accepted for use in residential applications, it is permitted in agricultural and industrial applications where health and environmental impacts are deemed to be minimal. This project focused on the reuse potential of this lumber for fabricating structural nail-lam members commonly used in agricultural post frame utility buildings. Significant amounts of waste CCA-treated lumber are generated by people replacing decks. Currently, this lumber is mostly landfilled as disposal waste. Finding other uses for this discarded material could reduce the waste burden of decking removed from service each year. For this study, 15-year-old decking material slated for removal and composed of nominal 2 by 6 CCA-treated Southern yellow pine (SYP; *Pinus* spp.) lumber was carefully reclaimed for structural post member fabrications. Similar structural nail-lam posts were fabricated from new, micronized copper azole–treated SYP lumber for comparative test purposes. Three experimental treatments were evaluated to examine mechanical performance in terms of bending strength, flexural rigidity, and ultimate compressive strength. The comparative results show slightly lower flexural performance but equivalent or slightly higher compressive strength for structural post member fabrications when constructed from the supply of reclaimed decking material. These results help to demonstrate the technical feasibility or reuse potential of recycled decking for this type of second-generation application.

Wood decks represent a very popular form of outdoor living space common to many residential dwellings. Since the early 1980s, these decks have extensively used lumber treated with chromated copper arsenate (CCA) preservative for protection against wood decay and termite (insect) attack. A study by Shook and Eastin (2001) indicated that 80 percent of all US residential decks used CCA-treated wood materials. This vast usage inventory of CCA-treated material is fast approaching the typical end-of-life cycle or, in other cases, early removal as premature termination from in-service use.

As outdoor structures, these residential decks are subject to the harsh effects of the sun, cyclic moisture exposure, severe weather, and foot traffic. As a result, the materials used in their construction are removed from service long before the onset of wood biological deterioration. Reasons for early replacement are typically serviceability-related issues, which may include decline of aesthetic appearance due to wood aging, development of unacceptable surface checking, increased maintenance requirements, or health

The authors are, respectively, Professor, Wood Products Engineering, Dept. of Agric. and Biological Engineering, Penn State Univ., University Park, Pennsylvania (jjj2@psu.edu [corresponding author]); Research Engineer, US Forest Products Lab., Madison, Wisconsin (rfalk@wisc.edu); Technical Director, National Wooden Pallets and Container Assoc., Alexandria, Virginia (bgething@palletcentral.com); and former Laboratory Research Assistant. John A. Tsirigotis is currently with Thrutubing Solutions, Montoursville, Pennsylvania (johnt31385@yahoo.com). This paper was received for publication in July 2012. Article no. 12-00076.

Forest Prod. J. 64(1/2):55–63.
doi:10.13073/FPJ-D-12-00076

concerns from arsenic exposure. Personal communication with several homeowners during this project confirmed their concern over arsenic-treated wood as a primary reason for an early removal of decking material.

For the above-mentioned reasons, CCA-treated decks have relatively short lives. Alderman (2001) found that decking had a life cycle of 13 years, while McQueen and Stevens (1998) determined that CCA-treated decks were often replaced after just 9 years of in-service use. Alderman et al. (2003) further elaborated the important factors related to the decking replacement life cycle. In contrast, many industrial wood products treated with oil-borne preservatives, such as railroad ties and utility poles, have service lives of 25 years or longer; however, aesthetic and health exposure issues are typically not drivers for removal in that class of products.

The short life cycle for residential wood decks and poor utilization of the treated wood resource generates a large amount of waste material and a growing disposal problem (Morrell 2004). Cooper (1993) estimated an annual disposal volume of 8 million m^3 (1990 estimate) for *all* treated wood products, while Bailey et al. (2004) determined that the removed volume of CCA-treated decking alone is about 2.4 million m^3/y. Even though this is a high volume of material, it is expected to grow. Projections by Cooper (1993) included 9 million m^3 (2000), 15 million m^3 (2010), and 16 million m^3 (2020), with 90 percent of the disposal burden coming from CCA-treated materials. Felton and De Groot (1996) predicted an even higher volume of 19 million m^3 for 2020. These projections may be conservative if public perceptions continue or intensify over the issue of arsenic-treated wood.

Residual CCA retention (Choi et al. 2004) and engineering property data (Bailey et al. 2004) have shown the reuse potential of discarded decking lumber. Results from the engineering testing of reclaimed CCA-treated decking and joists after 13 to 27 years of service indicated stiffness properties similar to those of new Southern yellow pine (SYP; *Pinus* spp.) preservative-treated lumber (Bailey et al. 2004). However, bending strength results were somewhat lower than those of new CCA-treated test material. Bailey et al. (2004) concluded that recovered CCA-treated wood could be used in many applications as ''second-generation products'' (SGPs), which include outdoor furniture, new decking or railings, and pallet components. Regulatory action has restricted the use of CCA-treated lumber in the residential consumer market, so some of these suggested uses are not allowed. However, industrial and agricultural uses are permitted. Pallets or wooden container packaging from discarded CCA-treated lumber might be viable SGP options, although they have relatively short life cycles.

Clearly, SGPs with longer life cycles would be helpful in extending the life of CCA-treated materials and reducing the flow of these materials to landfills. This is especially true when the wood is discarded due to degraded appearance or increased maintenance while significant residual strength is left in the wood. Nail-laminated (nail-lam) posts are widely used in agricultural and utility storage buildings and are manufactured as untreated structural members either partially (in-ground contact portion) or totally from preservative-treated wood (National Frame Building Association, 2013). As interior building frame members, the secondary life cycles, by design, are longer where posts manufactured from reclaimed decking could exhibit life expectancies exceeding those of the original decking. With a longer life cycle, nail-lam posts manufactured from reclaimed decking could be a viable and more advantageous recycling option for utilizing this waste material compared with previously researched SGP options.

While a literature review provided no information on the performance of mechanical fastener-laminated or nail-lam posts constructed from reclaimed CCA-treated lumber, the manufacture of adhesively laminated crossarms from decommissioned CCA-treated utility poles indicated that mechanical properties compared favorably to corresponding virgin wood with similarly constructed laminate section with respect to tested performances (Piao et al. 2009, 2010; Piao and Monlezun 2010).

This project was a preliminary effort to investigate the technical feasibility of reusing 2 by 6 lumber salvaged from wood decks as reclaimed material for fabricating structural nail-lam members commonly used in agricultural post frame utility buildings. Nominal 2 by 6 lumber is a typical size of lamination ply material used for these fabricated structural posts. Finding second-generation uses for this discarded material could help reduce the growing waste burdens of CCA-treated decking materials removed from service each year.

Materials and Methodology

Material selection and recovery

Remodeling contractors throughout the Commonwealth of Pennsylvania were contacted to identify residential projects involving wood decking removals. Selection criteria for collected decking included (1) CCA-treated SYP 2 by 6 lumber decking, (2) minimum age of 13 years, (3) unrestricted weather exposure, (4) treatment record verification and deck maintenance history, (5) high full-length lumber recovery potential, and (6) homeowner and contractor permission for research personnel to remove decking (to minimize damage and maximize the recovery of usable pieces).

Two decks meeting the above criteria were located in Centre County, Pennsylvania. Both decks had been in service 15 years and had relatively complete maintenance histories. Careful recovery yielded 102 pieces of 2 by 6 salvaged decking 3.6 m (12 ft) in length. The material recovered was mostly free of detectable deconstruction (removal) damage other than holes from the installation pattern of a paired set of 12D annular nails spaced 16 inches apart as the removed deck fasteners. Existing grade stamps typically observed after detachment confirmed the decking was No. 1 SYP, graded according to the Southern Pine Inspection Bureau (SPIB) rules.

Some recovered pieces lacked grade stamps or preservative treatment tags either due to deck water pressurized washings or, in the case of the treatment tags, removal during construction. Those pieces without lumber markings were excluded from further use in post fabrication treatments to assure that lower-strength species, especially Virginia pine (*Pinus virginiana*) and Pond pine (*Pinus serotina*), did not create a bias in the results of the mechanical performance evaluations. However, these unidentified Southern pine pieces of salvaged decking lumber were retained for purposes of adhesive screening trials.

The treatment tags found on the decking indicated that the original material preservative treatment was CCA, 4.01 kg/m^3 (0.25 pcf) retention (aboveground use), using the Wolman PLUS process. Wolman PLUS, a preservative treatment commonly used on SYP decking, consists of a primary impregnation with a water solution of copper chromated arsenate salt and a secondary impregnation with a water-repellent compound. Discussion with the homeowners indicated that they had routinely maintained the deck structure with an emulsified wax sealant (Olympic and Thompson ultraviolet inhibitor brands) and also periodically washed the deck surfaces with an unspecified wood-brightening cleanser (fortified with either a mildecide or a fungicidal additive).

In addition to the reclaimed decking lumber described above, new SYP decking was purchased from an engineered wood facility (RigidPly Rafters, Inc., Richland, Pennsylvania) to evaluate the performance of ''new'' treated lumber for study comparison. RigidPly produces glue-laminated structural posts for agricultural, commercial, and industrial building applications. This 2 by 6, No.1 SPIB lumber had been treated for above ground protection using micronized copper azole (MCA), but at a lower prescribed chemical preservative retention level (2.56 kg/m^3 [0.16 pcf]) than for the reclaimed decking. The Wolman PLUS treatment originally used in the reclaimed decking was unavailable in new lumber, because MCA (and other copper-based biocides) have largely replaced CCA (Freeman and McIntyre 2008). No effort was made to perform assays of residual CCA retention on the reclaimed lumber because of limited knowledge regarding the fungicidal compound in preservative chemical additions that may have resulted from in-service maintenance. Data on residual CCA retention was not deemed to be critical for this study given that salvaged decking materials may be reused in either partially preservative-treated or untreated designs of nail-lam posts as the aboveground portions of interior building service members.

Another deconstructed supply of contractor-removed SYP decking material (same 15-yr in-service age) had to be rejected, which did ultimately restrict the study with respect to available materials for treatment group replication. After closer inspection, the removed 2 by 6 lumber showed an abnormal fibrous surface condition. It was learned the deck owner had repeatedly used a concrete type of cleanser product. The concrete cleaner product mix included muriatic acid (38% HCl solution). This supply of material also showed clear signs of poor (uncontrolled) deconstruction, such as longitudinal fractures between nail installation holes. This suggested that forcible prying, as opposed to less damaging fastener removal, had been applied to mechanically detach the decking from the structural frame. This supply of potential research material included a different pattern of nail holes from that of the accepted decking lumber. Bailey et al. (2004) noted the potential of lower ultimate bending strength due to fastener holes that might act as flaws for fracture propagation.

Preparation of decking for testing and nail-lam post manufacture

Moisture equilibration.—During the deconstruction and salvage phase of the study, an electrical resistance meter (Delmhorst DXM-1) was used to measure in-place decking lumber moisture content (MC). Sampled readings at various depths showed significant MC variation (gradients) within the decking and, after removal, a moisture condition where the top surface MC was frequently higher than the bottom side of the salvaged piece of decking material. The upper surface measurements suggested MCs well above fiber saturation, while bottom measurements ranged far lower, from 16 to 21 percent, than the pine material in-service state of wood moisture with respect to environmental exposure. These MC readings are only approximations, because the DXM-1 meter was not calibrated with an internal device adjustment for moisture measurement of CCA salt-impregnated wood (ASTM International 2004a).

To verify field observations, oven dry MC tests were performed according to ASTM D4442 (ASTM International 2004b). The MC at the core of the decking pieces showed a fairly consistent 12 $\pm$ 2 percent, while the top surface MC ranged from 20 to 69 percent and the bottom surface from 14 to 22 percent. Based on ASTM D4442 observations of wood MC disparity and to achieve standardized mechanical property test results, the supply of reclaimed lumber was equalized in an environmental chamber (68% relative humidity [RH] and 18.3°C [65°F]) until a constant weight basis was reached within the stored lumber pieces. Of the original decking removed from in-service, 11 pieces experienced moderate to severe lumber distortion (twist or bow as lumber grade–limiting defects) and were removed from further use. The new SYP decking was conditioned in the same manner to standardize the MC of the new, freshly treated (MCA) lumber used for comparison (control) in the experimental fabrication of structural post member specimens.

Initial stiffness testing.—After moisture equilibration, all reclaimed decking pieces and the supply of new, MCA-treated material were measured to determine lumber flatwise stiffness as both the long-span static bending modulus of elasticity (MOE_b) and the wood material dynamic modulus of elasticity (MOE_d). MOE_b was determined using a midspan concentrated load (4.04 kg constant weight unit [8.90 lb]) and manual load to displacement dial gauge (0.025-mm [0.001-in.] measurement precision) for static measure of beam deflection with subsequently computed elastic apparent flexure modulus value, whereas MOE_d measurements were directly taken using a Metriguard Model 340 transverse E-computer (Metriguard 2007).

Surface planing.—After the above-described moisture stabilization and the initial stiffness testing, each ''aged'' piece of 2 by 6 decking was run through a wood surfacing planer to remove the weathered faces, deck finish, or any other surface condition that might severely impact adhesive performance. The amount of wood removed was based in part on the results of adhesive screening trials (described below).The planer was adjusted to remove 1.52 mm (0.062 in.) on each face with approximately 8 to 10 knife cuts per inch. This amount of planer reduction to the ''aged'' faces was found to remove 90 to 100 percent of the wood surface checks. Any residual checking defect observed was generally less than a measurable depth of 0.07 mm (0.03 in.).

This same preparation was applied to both the reclaimed and new lumber pieces. This was essential to ensure the same ply thickness and consistent section size of fabricated nail-lam specimens. Following this processing step to reclaim the lumber (i.e., to remove the aged surface material), the reduced-thickness pieces were visually inspected according to SPIB rules for permissible knot defects to determine any change in structural grade. Only a few pieces showed change of permissible knot sizing, with improvement of lumber structural quality to Select Structural (SS). These SS grade 2 by 6 pieces of lumber were discarded.

Post planing lumber stiffness testing.—After planing, the apparent MOE_b was measured again on a representative subsample (15 random pieces) of the reclaimed lumber. Because of observed moisture (high to low) and more intense in-service mechanical and weather aging exposure from the top to the bottom, MOE_b was also measured in both decking installation orientations (top and bottom). Results indicated that planer removal of ''weather-aged material'' had no discernible effect on observed values of the reclaimed lumber MOE_b. Also, no statistical difference (95% confidence level) was found in measured apparent stiffness between the two lumber test orientations and the two applied MOE measurement methods. This indicates that either static deflection tests or dynamic material MOE testing has the potential to be used in screening reclaimed decking lumber for commercial nail-lam production.

Adhesive screening trials

Prescreening adhesive trials were conducted to determine if there was a benefit of planing the wood surfaces for binder-enhanced nail-lam performance as well as to gain insight on the substrate bonding problems that might occur with both the preservative treatment and the applied decking finishes (maintenance treatments). A room temperature cure phenol resorcinol formaldehyde (PRF) resin (Arclin 4001/5830S) and a mastic elastomeric construction adhesive (Liquid Nails) were used to bond decking lumber with three difference surface preparation treatments: (1) weathered-to-weathered (original condition aged in-service as the bond surfaces), (2) weathered-to-planed (single reclaimed surface), and (3) planed-to-planed (both material surfaces reclaimed) bonding of both freshly dressed wood adherends. Bonded specimens were stored (68% RH and 18.3°C [65°F]) for a minimum of 2 weeks to assure adequate bond development before evaluation of glue-line shear load capacity.

A five-point bending test (FPBT) was used to evaluate cured glue-line shear strength (Rammer et al. 1996) as the measure of bond performance. For single glue-line FPBT testing, the specimen lamination materials were first planed for major thickness adjustment on the surface opposite of the intended glue-line adherend face and then underwent planer surface removal down to the final 1.91-cm (0.75-in.) lamination thickness. Final specimen dimensions equaled 5.94 by 45.72 cm (2.34 by 18 in.). Ripping the 13.97-cm (5.5-in.) width lumber provided a matched set of material for the individual bonded FPBT specimens. In all instances of adhesive application, this was done within an hour after the intended adherend surface preparation treatment. Specimen lamination lumber as the bond test material was selected to be mostly clear (knot-free) and to have a relatively straight grain (minimum 1-in-12 slope of grain [SOG] as cut-to-length SOG material quality).

Specimen length for reaction/support span to depth (d) was held at 5d to yield high percentages of beam shear failure (Rammer et al. 1996). Despite this, some FPBT specimens showed localized compression sufficient to influence the resultant beam shear failure mode and were removed from the test population. These constraints explain some of the unequal specimen replications reported in the adhesive screening results. The first preparation treatment (weathered-to-weathered grouping with bonding of the PRF resin) was intentionally stopped after only seven completed tests instead of the originally planned 20 FPBT quantitative replications. Additional PRF tests were stopped after the initial series of glue-line tests showed unacceptable bonding results with respect to very shallow wood failure modes critical not only for maximum shear load capacity but for durable structural performance over time.

Nail-lam post test specimen construction and fabrication

To study post member performance, three layups based on MOE were devised: (1) three-ply unspliced construction with no consideration of lumber MOE (i.e., random ply placement; Type 1 treatment), (2) placement of higher-MOE plies as the outer laminations (Type 2 treatment), (3) placement of higher-MOE plies as the outer laminations but with applied adhesive glue lines between the composite section laminations (Type 3 treatment). The adopted post member construction with specimen fabrication strategy focused on full-length lumber (lamination without joints; e.g., unspliced). This was deemed to be prudent to avoid the influence of a splicing factor on ultimate load-bearing capacity and/or composite stiffness behavior and to control or restrict further variability in post performance.

Because of piece loss during remanufacture and, more importantly, the rejected supply of salvaged SYP decking 2 by 6 lumber, only nine reclaimed decking posts could be constructed for each layup type. Three replications of posts from the new decking were constructed for each layup type. To control randomization within the post fabrication treatments, the available inventory of reclaimed 2 by 6 research material was ranked from lowest to highest MOE_b, and every first to third piece of lumber was assigned to a layup type (normalized redistribution of sample lumber stiffness to each independent treatment group). Efforts were taken before fabrication to secure an additional supply of reclaimed lumber as research inventory material. However, this effort failed to isolate the same grade (SPIB No. 1) and in-service (15-yr age) nominal 5.08-cm (nominal 2-in.)-thick Wolman PLUS SYP lumber. Several remodelers had pending removal projects involving decks close to 15 years old but with 5/4-inch-thick board construction as opposed to the previously specified criteria for study selection of aged 2 by 6 SYP decking lumber material.

Layups as test evaluation specimens were fabricated using both the reclaimed and the new 2 by 6 lumber exclusively following industry-adopted standard nailing pattern recommendations (American Society of Agricultural and Biological Engineers 2008). Nails for post lumber mechanical lamination were applied with a Bostich pneumatic nailer and were 3.25 inches in length by 0.12 inch in diameter (12D) smooth shank fasteners. Air pressure was adjusted and monitored to prevent overdriving the installed nail fasteners for ply lamination connection. The 12D nails for three-ply laminated sections were installed using a double fastener installation with a 22.9-cm (9-in.) spacing pattern. For Type 3 post members, the elastomeric adhesive was applied using a caulking gun with manual deposition of three equivalently spaced, continuous beads of Liquid Nails glue. In all instances of post specimen fabrication, bar clamps were utilized for all three fabrication types in the experimental treatment groups to slightly compress the laminations together and to aid in holding the edge alignment (control ply slippage) while applying the sequence of installed lamination fasteners.

Adding adhesive to nail-lam posts is thought to improve their structural performance (Ohio Timberland Products 2011). Based on the adhesive pretrials described above, the Liquid Nails adhesive was selected for post members to examine potential performance enhancements via added adhesive glue-line lamination. Each post was stored for 14 days, a duration similar to that used in other nail-lam structural research as the mechanical test performance protocol (Williams et al. 1994). A 14-day period was believed to be an adequate or reasonable time to assure adhesive lamination cure with solidification of the mastic type of adhesive binder within the three-ply member constructed composite sections.

Mechanical testing of nail-lam posts

Both strength and stiffness properties are important in post frame designs, because the nail-lam posts must have adequate structural capacity for resistance both to flexure loading and to axial compressive forces. Therefore, ultimate extreme fiber stress bending and compressive parallel-to-grain strengths combined with fabricated post member stiffness were included for experimental testing in the post member performance evaluation program.

The stiffness of the fabricated posts was nondestructively load tested (less than two-thirds of the estimated maximum moment capacity). First, the post specimens were placed in a universal test machine (UTM) at the vertical lamination test orientation to determine edgewise flexural rigidity ($EI_{y\text{-}y}$). Then, the post specimens were rotated in place to the horizontal lamination orientation to determine flatwise flexural rigidity ($EI_{x\text{-}x}$), with loading taken to maximum force for destructive failure. Specimen failure was defined as the post member section no longer carrying a higher UTM force load. ASTM D198 (ASTM International 2008) load arrangement and test procedures were followed using a computer-aided SATEC UTM with a capacity of 448 kN (100 kip). Derived composite EI values were obtained from linear regressions of the independent post member load-deformation response curves. The fabricated specimens were approximately 10.8 by 14 cm (4.25 by 5.5 in.) in cross section and were flexure load tested over a 3.35-m (11-ft) span between the test reaction supports.

After completion of flexural testing, a paired set of compression specimens 60.3 cm (23.75 in.) in length (l) were cut from the visually undamaged beam end portions. With a least dimension of $r = 10.8$ cm, the specimens were tested as short column members ($l/r < 17$) at a constant loading rate according to ASTM D198 (ASTM International 2008). The column dimension of 14 cm was reduced 23 percent to 10.8 cm in width to correspond to the 44.8-kN capacity of the SATEC UTM so that parallel-to-grain failure could be induced. This percentage reduction was based on anticipated ultimate compressive strength for the major SYP species. Only two specimens did not fail with the SATEC UTM, and these were subsequently tested to ultimate stress failure in a Tinius Olsen mechanical test machine with higher force capacity (532 kN [120 kip]). Computer-recorded load-to-deformation curves showed these specimens had not reached their linear elastic capacity and were acceptable for retesting to obtain an accurate value of ultimate post capacity strength.

Results and Discussion

Long-span decking stiffness (observed differences in lumber MOE)

Summary statistics for apparent lumber stiffness, as measured full-length material properties of MOE_b and MOE_d, are presented in Table 1. The results indicate only a slight difference in MOE_b and MOE_d for both the reclaimed and new decking. As previously noted, the results with the two MOE collection methods were not significantly different so that dynamic MOE or static deflection could be applied to salvaged CCA-treated decking supplies of lumber to identify acceptable material stiffness for structural post member fabrication. However, MOE_d determinations allow a slightly more rapid decision to either accept or reject (e.g., to eliminate individual pieces from further recycling consideration and thus avoid wasteful steps with added cost to process laminations for post member production).

Overall, the new (MCA-treated) lumber acquired for post fabrication exhibited a 30 percent higher average MOE_b (numerically significant) than the reclaimed CCA-treated decking along with a much lower coefficient of variation (COV). Bailey et al. (2004) reported ''aged'' decking compared favorably (statistically similar) with freshly CCA-treated SYP. However, their ASTM D198 tests were restricted to 60-inch spans for material evaluation that, where possible, included the controlling defect for the 13- to 27-year-old 2 by 6 decking lumber along with further evaluation of 5/4 by 6 aged board materials taken from service use. Falk et al. (1999), with ASTM D198 full-span evaluation testing, found that ''aged'' deconstructed SYP 2 by 10 but untreated No. 2 structural quality lumber had the same stiffness but lower second-generation lumber product performance in terms of in-grade bending strength.

Closer inspection of the RigidPly lumber showed the acquired SYP material might be more predisposed to including higher-stiffness longleaf pine (*P. palustris*) and slash pine (*P. elliottii*). Limited representation of all the major SYP species within the sample does help to explain the lower variability of computed COVs for the MOE_b and MOE_d (Table 1). In contrast, the ''aged'' supply of SYP decking was weighted more toward lower mechanical performance loblolly pine (*P. taeda*) and shortleaf pine (*P. echinata*) lumber material. In addition, the new supply of 2 by 6 processed lumber was made of slower-growth wood (e.g., higher ring counts per inch). Accordingly, for lower-

Table 1.—Static bending (MOE_b) and dynamic bending (MOE_d) of reclaimed decking and new 2 by 6 lumber.[a]

	Reclaimed decking (N/m^2) ($n = 81$)		New decking (N/m^2) ($n = 27$)	
	MOE_b	MOE_d	MOE_b	MOE_d
Mean	1.06E10	1.00E10	1.29E10	1.33E10
COV (%)	26	25	18	17

[a] To convert values to pounds per square inch, divide by 6,894.7.

MOE lumber, the measured modulus stiffness may relate more to an inherent material quality and species mix as opposed to a comparative material MOE decline due to exterior weather exposure.

Overall, if the CCA-treated lumber was uniquely a loblolly/shortleaf wood mixture, this could account for a 12 percent lower inherent flexure stiffness within the reclaimed supply of in-grade SYP study material. This is based on the reported true MOE values for these pine species (Kretschmann 2013). Further data interpretation showed the new, freshly MCA-treated supply of SYP lumber had a true flexural E value of 1.99×10^6 psi, or 4.7 percent greater than the in-grade design stiffness corresponding to the highest-quality Dense Select Structural SYP lumber product material (American Wood Council 2005). In comparison, the average flexure modulus (shear-free adjusted to true E value) of the reclaimed CCA-treated sampling equated to 1.64×10^6 psi and closely matched SPIB No. 1 lumber product design stiffness at 1.70×10^6 psi (–3.7% difference). Despite being similar to in-grade SPIB No. 1, much higher characteristic stiffness is shown by the new MCA-treated lumber, and any further experimental comparisons of the ''aged'' mechanical performance in terms of strengths should recognize this potential difference in quality between the two supplies of experimental material.

Adhesive surface preparation bonded performance

The influences of surface preparation of the reclaimed wood materials and the two experimental bonding adhesives are summarized in Table 2. Both adhesives yielded higher observed glue-line shear strength with removal of the ''weathered'' surfaces. Shear strength increases of 13 and 53 percent were observed for the elastomeric adhesive and PRF, respectively. Performance improvement for beam glue-line shear was also shown by the lower COVs for both the elastomeric and PRF lamination adhesive. The observed percentage increases in bonded shear strength capacity indicates that reclaiming the surfaces is highly advisable should post member fabrication include application of an adhesive binder.

Observations on interfacial glue lines, particularly those of the planed-to-weathered surfaces, showed a correspondingly greater depth of wood failure on the planed surface. The unplaned surfaces showed very shallow wood failure, suggesting inadequate adhesive wetting or a problem with adhesive penetration. Although lower shear strengths were exhibited, the elastomeric adhesive is viewed as the most practical adhesive for nail-lam post production. Overall, elastomeric adhesives require less stringent surface preparations for development of adhesive bond strength, have good gap-filling properties, and involve a mating pressure that can be adequately applied by the installed nail fastener (Frihart 2013). Also noteworthy in comparison to other synthetic resins, elastomeric adhesives are generally insensitive to the effect of CCA on adhesive performance for wood bonded connections (Pellicane 1999).

Table 2.—Summary of adhesive pretrial five-point bending test glue-line shear strength results.

Surface preparation	Adhesive type[a]	n	Avg. shear strength (N/m^2)[b]	COV (%)
Planed-to-planed	EM	14	7.89E6	12
	PRF	15	8.90E6	22
Planed-to-weathered	EM	17	7.15E6	24
	PRF	15	6.55E6	23
Weathered-to-weathered	EM	17	7.01E6	25
	PRF	7	5.82E6	30

[a] EM = elastomeric adhesive (Liquid Nails); PRF = phenol resorcinol formaldehyde.

[b] To convert values to pounds per square inch, divide by 6,894.7.

Mechanical performance results for tested post members and summary of construction lumber MOE properties

Table 3 summarizes the average inherent lumber stiffness, MOE_b, within the three experimental treatments. The results show the adopted strategy of randomization was effective in reducing material variability among the fabricated composite treatments and within post member specimen test groups to enhance statistical sensitivity in detecting treatment effects relative to the tested mechanical strength properties.

Table 4 provides the descriptive statistics for the various treatment performance evaluations with post members composed of reclaimed CCA-treated laminations in comparison to a pooled observation mean, with three specimens of each treatment type included in the statistical average and nine total test observations of new MCA-treated post member performance. This table also summarizes the various test program evaluations with respect to differences in mechanical performance between the experimental structural post members.

Observations of mechanical strength differences.—Examination the descriptive statistics (Table 4) shows ultimate flexural strengths are generally lower in the reclaimed decking lumber post treatments compared with posts constructed with new MCA-treated lumber. Overall, the greatest bending strength difference was a 16 percent lower average performance of the Type 3 post treatment (i.e., optimized with added glue fabrication). However, this performance difference may relate more to the inherent modulus of rupture (MOR_b) for the material strengths of longleaf and slash pine. MOR_b (12% conditioned MC) properties of these pine species are approximately 19 percent higher than for shortleaf and loblolly pine (Kretschmann 2013). Any performance enhancement of the optimized treatments (Type 2 and Type 3 post fabrication) with higher MOE_b outer lamination placement or use of adhesive glue line (Type 3 reclaimed posts) to contribute higher strength appears to be absent from the constructed sections with respect to ultimate post flexural

Table 3.—Average lumber static bending (MOE_b) within the constructed post experimental treatment groups.[a]

	Reclaimed posts (N/m^2) (n = 27)[b]			New posts (N/m^2) (n = 9)
	Type 1	Type 2	Type 3	
Mean	1.07E10	1.06E10	1.08E10	1.29E10
COV (%)	10	5	6	2

[a] To convert values to pounds per square inch, divide by 6,894.7.

[b] Type 1 = random-MOE laminations; Type 2 = high-MOE outer laminations; Type 3 = applied adhesive.

Table 4.—*Descriptive statistics of the tested mechanical performance for the three experimental treatments of fabricated nail-laminated posts.*[a]

	Bending strength				Compressive strength			
	Reclaimed posts (N/m^2) ($n = 27$)			New posts (N/m^2) ($n = 9$)	Reclaimed posts (N/m^2) ($n = 27$)			New posts (N/m^2) ($n = 9$)
	Type 1	Type 2	Type 3		Type 1	Type 2	Type 3	
Mean	4.50E7	4.48E7	4.36E7	5.02E7	3.27E7	3.25E7	2.97E7	3.09E7
COV (%)	17	11	13	8	12	9	17	10

	Flexural rigidity ($EI_{y\text{-}y}$)				Flexural rigidity ($EI_{x\text{-}x}$)			
	Reclaimed posts (N/m^2) ($n = 27$)			New posts (N/m^2) ($n = 9$)	Reclaimed posts (N/m^2) ($n = 27$)			New posts (N/m^2) ($n = 9$)
	Type 1	Type 2	Type 3		Type 1	Type 2	Type 3	
Mean	7.10E11	6.58E11	7.65E11	8.69E11	1.66E11	1.96E11	3.17E11	1.74E11
COV (%)	14	25	12	19	20	9	28	9

[a] Type 1 = random-MOE laminations; Type 2 = high-MOE outer laminations, Type 3 = applied adhesive. To convert values to pounds per square inch, divide by 6,894.7.

load capacity. Observations during flexural loading and examinations of the destructive test members with the reclaimed lumber post specimens did not suggest nail holes were systematic to influence or limit ultimate stress the critical fracture initiation or propagation the beam section failure mode.

Despite the lower flexural strength of reclaimed CCA-treated post members compared with new MCA-treated post members, possibly related to the above-described bias (e.g., higher-MOR material), the compression test evaluation results were quite different. In contrast, compression performances of the reclaimed posts were much more similar, despite a 15 percent lower mechanical parallel-to-grain strength associated with shortleaf and loblolly materials. Type 1 and Type 2 reclaimed posts exceed, while Type 3 constructed posts have a modest 4 percent lower performance difference from, the compression loading capacity of the replacement lumber–fabricated post members. These results show the reclaimed posts would compete favorably with structural members fabricated using new lumber where compression controls the in-service design application.

Observations of composite stiffness.—Both $EI_{y\text{-}y}$ and $EI_{x\text{-}x}$ for Type 1 and Type 2 fabrication posts are lower than the reported observed composite stiffness values of the pooled average new post performance. Undoubtedly, the higher-quality MOE_b lumber represented by the new MCA-treated lumber contributes to this observed difference in post stiffness behavior.

Type 1 and Type 2 unglued posts, combined as a test group, had an $EI_{y\text{-}y}$ performance 27 percent lower on average compared with the pooled test observation of flexural rigidity for the new lumber–fabricated post performance. Some discernible improvement was observed in edgewise stiffness performance with the adhesive application for the Type 3 posts. The benefit of adhesive gluing to enhance stiffness behavior is most evident in the higher flatwise $EI_{x\text{-}x}$ performance. Type 3 posts, compared with the same use of optimized lamination placement treatment (Type 2 post members), had a nearly 62 percent greater composite $EI_{x\text{-}x}$ on average. However, this fabricated group of post members also showed an unexpectedly large performance variability (COV = 28%).

This large performance variability may be explained by visual observations of the post failure zones within some of the lamination bonded specimens immediately after destructive testing. Some glue lines of the three-ply constructed sections showed evidence of incomplete bond cure (e.g., construction glue solidification). Some specimens had one or two glue lines where the elastometric adhesive was not hardened enough to fully develop shear load transfer resistance. Lack of solidification was more evident near the laminated centerline, and accordingly, a longer period from post fabrication to destructive testing would have been appropriate. Adhesive trials with smaller width and single glue-line bonded specimens showed good mastic hardening after 14 days. This inconsistency could be significant where potential improvements of composite performances are being conservatively reported with the addition of an adhesive.

Statistical analysis of the post fabrication treatments

Table 5 presents the results of nonparametric statistical analyses performed to examine significance between the type of post fabrication (treatment) composed of reclaimed 15-year-old CCA-treated lumber, new and freshly MCA-treated lumber, and comparatively, the reclaimed versus new post performance. Paired t tests with parametric hypothesis testing were restricted due to unequal sampling variances and lack of normal data distributions. Instead, nonparametric analyses were performed utilizing the Mann-Whitney U test ($\alpha = 0.05$; Mann and Whitney 1947).

Table 5 shows that most comparisons have large P values (i.e., no detected significant differences between the varying experimental treatments). The most notable exception is the composite post $EI_{x\text{-}x}$ mechanical property for both reclaimed and new post members, for which there appears to be a significant treatment type response that suggests a performance-enhancing effect from the addition of the adhesive glue line. With respect to compression and bending strength properties, the nonparametric analyses tend to show no significant difference between treatment type and, more importantly, between reclaimed versus new lumber material.

Table 5.—Summary of nonparametric statistical analyses (Mann-Whitney U tests) for significance among treatment types and between reclaimed to new lumber nail-laminated post mechanical performance.

Reclaimed material		New material		Reclaimed vs. new material	
Performance comparison	*P* value	Performance comparison	*P* value	Performance comparison[a]	*P* value
		Bending strength			
Type 1 vs. Type 2	0.9616	Type 1 vs. Type 2	0.6625	Type 1 vs. New	0.1124
Type 2 vs. Type 3	0.8099	Type 2 vs. Type 3	1.0000	Type 2 vs. New	0.0637
Type 1 vs. Type 3	0.5962	Type 1 vs. Type 3	0.6625	Type 3 vs. New	0.0341[b]
		Compression strength			
Type 1 vs. Type 2	0.8619	Type 1 vs. Type 2	1.0000	Type 1 vs. New	0.2339
Type 2 vs. Type 3	0.1101	Type 2 vs. Type 3	0.5940	Type 2 vs. New	0.1334
Type 1 vs. Type 3	0.0684	Type 1 vs. Type 3	0.5752	Type 3 vs. New	0.4376
		Composite post $EI_{y\text{-}y}$			
Type 1 vs. Type 2	0.9648	Type 1 vs. Type 2	0.8273	Type 1 vs. New	0.0193[b]
Type 2 vs. Type 3	0.3094	Type 2 vs. Type 3	1.0000	Type 2 vs. New	0.0104[b]
Type 1 vs. Type 3	0.1575	Type 1 vs. Type 3	1.0000	Type 3 vs. New	0.1451
		Composite post $EI_{x\text{-}x}$			
Type 1 vs. Type 2	0.0047[b]	Type 1 vs. Type 2	0.0809[b]	Type 1 vs. New	0.2673
Type 2 vs. Type 3	0.0047[b]	Type 2 vs. Type 3	0.0809[b]	Type 2 vs. New	0.2673
Type 1 vs. Type 3	0.0062[b]	Type 1 vs. Type 3	0.0809[b]	Type 3 vs. New	0.8533

[a] For bending strength, compression strength, and composite post $EI_{y\text{-}y}$, comparison between reclaimed material and new material is treated as one large group ($n = 9$). For composite post $EI_{x\text{-}x}$, comparison between reclaimed material and new material is treated as individual groups ($n = 3$).
[b] Significant difference.

Conclusions

The experimental testing of nail-lam posts constructed from reclaimed 2 by 6 lumber decking indicates that this material has potential for reuse in this engineered application. While the engineering properties of evaluated flexural strength and flexural rigidity (post member stiffness) were somewhat lower, compression strength was very comparable, if not higher, to that of similarly constructed nail-lam posts fabricated with new lumber material.

Despite the higher material quality represented by the supply of new MCA-treated SYP lumber, the data collected support the conclusion that use of reclaimed SYP lumber as nail-lam post members is a viable recycling opportunity. Such use will reduce the amount of CCA-treated material sent to the landfill and will help to extend and sustain our nation's wood resources.

A few technical limitations in the reuse of this discarded CCA-treated lumber to manufacture second-generation post members for agricultural and industrial building applications were observed. Some material losses were experienced after deck removal, mainly from a high moisture gradient (exterior exposure factor) and then from development of grade-limiting lumber bow and twist defects during wood drying. This loss could be controlled by deconstruction checks of the in-service moisture and applying an appropriate control measure after detachment from the existing deck fastener restraint. Utilizing MOE measurement methods for screening could be effective in sorting the material with acceptable from that with unacceptable stiffness for the nail-lam structural laminations. Lower-quality lumber may have other potential recycling uses in deep section glued-laminated timber where mixed-length decking could be finger-jointed as an acceptable core lamination material.

Acknowledgments

This research was financially supported a grant from the US Forest Products Laboratory (Madison, Wisconsin) and conducted through the Penn State University (PSU) Agricultural Experiment Station (University Park, Pennsylvania). The authors thank the various deck remodeling contractors who notified PSU staff of rehabilitation projects useful for collection of experimental material. The authors appreciate the willingness of homeowners to cooperate with PSU personnel during on-site inspections and to allow the researchers special permission to conduct controlled deconstruction. Gratitude is also expressed the North American Deck and Railing Association (Quakertown, Pennsylvania) for their support of the research objectives.

Literature Cited

Alderman, D. R. 2001. An investigation into attitudes towards recycling CCA-treated lumber. PhD dissertation. Virginia Polytechnic Institute, Blacksburg.

Alderman, D. R., R. L. Smith, and P. A. Araman. 2003. A profile of CCA-treated lumber removed from service in the Southeastern United States decking market. *Forest Prod. J.* 53(1):38–45.

American Society of Agricultural and Biological Engineers (ASABE). 2008. Design requirements and bending properties for mechanically laminated columns. ANSI/ASAE EP559 DEC1996 (R2008). ASABE, St. Joseph, Missouri.

American Wood Council. 2005. National Design Specification (NDS) Supplement: Design values for wood construction. American Forest & Paper Association, Washington, D.C.

ASTM International. 2004a. Standard test methods for use and calibration of hand-held moisture meters. ASTM D4444. ASTM International, West Conshohocken, Pennsylvania.

ASTM International. 2004b. Standard test methods for direct moisture content determination of wood and wood-based materials. ASTM D4442. ASTM International, West Conshohocken, Pennsylvania.

ASTM International. 2008. Standard test methods of static tests of lumber in structural sizes. ASTM D198. ASTM International, West Conshohocken, Pennsylvania.

Bailey, D. S., R. L. Smith, and P. A. Araman. 2004. An analysis of the physical properties of recovered CCA-treated wood from residential decks. *Wood Fiber Sci*. 36(2):278–288.

Choi, S., J. N. R. Ruddick, and P. Morris. 2004. Chemical redistribution in CCA-treated decking. *Forest Prod. J*. 54(3):33–37.

Cooper, P. A. 1993. Disposal of treated wood removed from service: *In:* The Issues. Environmental Considerations in the Use of Pressure Treated Wood Products. Forest Products Society, Madison, Wisconsin.

Falk, R. H., D. Green, and S. C. Lantz. 1999. Evaluation of lumber recycled from an industrial military building. *Forest Prod. J*. 49(5):49–55.

Felton, C. C. and R. C. De Groot. 1996. The recycling potential of preservative-treated wood. *Forest Prod. J*. 46(7/8):37–46.

Freeman, M. H. and C. R. McIntyre. 2008. A comprehensive review of copper-based wood preservatives with a focus on new micronized or dispersed copper systems. *Forest Prod. J*. 58(11):6–27.

Frihart, C. R. 2013. Wood adhesion and adhesives. http://www.fpl.fs.fed.us/docmnts/pdf2013/fplfrihart001.pdf. Accessed June 2012.

Kretschmann, D. E. 2013. Mechanical properties of wood. http://www.fpl.fs.fed.us/docmnts/pdf2013/fplgtr190/chapter_05.pdf. Accessed June 2012.

Mann, H. B. and D. R. Whitney. 1947. On a test whether one of the two random variables is stochastically larger than the other. *Ann. Math. Stat*. 18(1):57–60.

McQueen, J. and J. Stevens. 1998. Disposal of CCA-treated lumber. *Forest Prod. J*. 48(11/12):86–90.

Metriguard. 2007. Precision testing equipment for wood. Catalog 34-1. Metriguard, Inc., Pullman, Washington. 70 pp.

Morrell, J. J. 2004. Disposal of treated wood products in the US: Limited options and abundant challenges. *In*: Environmental Impacts of Preservative Treated Wood Conference, February 8–11, 2004, Orlando, Florida.

National Frame Building Association. 2013. Post-frame advantage. http://www.postframeadvantage.com/pub/Durable. Accessed June 2012.

Ohio Timberland Products. 2011. Nail-Lam ''PLUS'' columns. http://www.ohiotimberland.com/literture.html. Accessed June 2012.

Pellicane, P. J., G. C. Robinson, and D. Reichler. 1999. Elastomeric adhesives in wood connections: Short-term behavior. *J. Mater. Civ. Eng*. 1999:11:266–272.

Piao, C., M. Gibson, T. F. Shupe, and W. A. Nipper. 2010. Laminated crossarms made from decommissioned chromated copper arsenate–treated utility pole wood. Part II: Preservative retention, glue-line shear, and delamination. *Forest Prod. J*. 60(7/8):659–667.

Piao, C. and C. J. Monlezun. 2010. Laminated crossarms made from decommissioned chromated copper arsenate–treated utility pole wood. Part I: Mechanical and acoustic properties. *Forest Prod. J*. 60(2):157–165.

Piao, C., C. J. Monlezun, C. Y. Hse, and W. A. Nipper. 2009. Glue-line bonding performance of decommissioned CCA-treated wood. Part II: Retreated with CCA. *Forest Prod. J*. 59(10):31–39.

Rammer, D. R., L. A. Soltis, and P. K. Lebow. 1996. Experimental shear strength of unchecked solid-sawn Douglas-fir. Research Paper FPL-RP-553. USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin. 33 pp.

Shook, S. R. and I. L. Eastin. 2001. A characterization of the US residential market. *Forest Prod. J*. 51(4):28–36.

Williams, G. D., D. R. Bohnhoff, and R. C. Moody. 1994. Bending properties of nail-laminated posts. Research Paper FPL-RP-528. USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin. 16 pp.