The Potential of Wood-Based Composite Poles

Todd F. Shupe
Cheng Piao
Lousiana State University AgCenter
Baton Rouge, LA

Chung Y. Hse
USDA Forest Service
Pineville, LA

ABSTRACT

Wood-based composite utility poles are receiving increasing attention in the North American pole market. This interest is being driven by many increasing factors such as increasing: (1) disposal costs of solid wood poles, (2) liability and environmental concerns with traditional means of disposal of solid wood poles, (3) cost and concerns of long-term availability of pole-sized timber, and (4) environmental concerns and awareness of the general public regarding recycling, forest sustainability, ground water contamination, etc. There have been several research projects over the years that have explored various methods of developed wood-based composite poles with varying degrees of success. This paper summarizes the past and current efforts of developing wood-based composite utility poles with an emphasis on recent collaborative efforts based at the Louisiana State University AgCenter. The omission of any wood-based composite pole efforts is unintentional, and we ask readers to bring such omissions to our attention.

INTRODUCTION

The use of wood poles in communication systems dates back to 1844 when the first commercial telegraph system was constructed from Washington, D.C., to Baltimore, MD (Panshin et al. 1950). This marked the beginning of pole production in the forest products industry. After about 40 years, poles were first used in another transmission system - the electrical power transmission lines. Wood poles are now widely used in communication and power transmission systems around the world. In 1998, about 130 to 150 million wood poles were used to carry overhead cables for electric, telephone and cables in the United States (Canadian Institute of Treated Wood (CITW) 1998). Recent estimates are that there are more than 10 million utility poles in service in North America – most of them are made from softwood species (USDA FPL 2008). Both communication and electrical companies consume about two million wood poles in annual construction of new lines. One to two million poles are used to replace poles in service due to decay and/or mechanical damage (Erickson 1994).

Wood is an ideal material for poles. With the development of new materials and processing techniques, poles made from materials other than wood entered in the transmission and distribution markets. Spun concrete, light duty steel, and fiberglass are the three important sources of such materials. Since wood is subject to rot, decay and degradation, all of these materials are more durable than wood. Moreover, the weight of fiberglass poles is even lighter than wood poles. Nonetheless, wood is still the material of choice for poles in the U.S. This is due to the intrinsic attributes of wood. Compared to other poles materials such as steel and concrete, wood is produced from a renewable natural resource, which is resilient and extremely resistant to oxidation, corrosion, fatigue, crumbling, and spalling. If properly preservative-treated, wood is protected against the biological agents that cause it to weaken and collapse in nature, (i.e., fungi and termites). Wood poles are easily climbed, more than adequately strong and easily machined. The decisive factor that wood is preferred over other materials is its low cost. Engineering Data Management Inc. (EDM) compared life-cycle costs of four types of poles (wood, light-duty steel, fiberglass (FRT), and spun concrete), and the results indicated that wood poles are the least expensive life-cycle choice in most distribution pole categories. Although post-construction costs, such as inspection, maintenance, repair, replacement, and disposal, are higher, wood poles remain the cost-effective choice. (AWPI 1996)

However, due to the ever-increasing population and demand for wood, logs that are suitable for transmission and distribution poles are becoming increasingly scarce. The availability of this pole-size timber has severely diminished (Marzouk et al. 1978; Miller and Graham 1970). On one hand, the wood pole industry faces the challenges of rising costs and losing market share. On the other hand, the power and telecommunication industries have tried to find a satisfactory substitute for the solid wood pole.

Orthotropic and laminated wood composite poles may be one of the solutions to the current pole resource problem. Wood composite poles consist of wood strips bonded with synthetic resin. The poles have polygonal cross-sections and a tapered form. Since the strip thickness is less than pole radius, composite poles are hollow inside. For a pole with a specific diameter, number of strips (NOS) and strip thickness are variables; for different applications, composite poles can be made into any diameter and length. Pole strips are normally finger- or butt-jointed to make them to pole length. The glue used is resorcinol-formaldehyde resin, which is weatherproof and can set at room temperatures.

There are multiple advantages of composite poles over solid wood poles. It normally takes 50 to 60 years for a tree to grow to a pole size. For composite poles, the strips can be materials of various ages and sources. Therefore, the material cost of composite poles is much lower than solid poles. The weight of hollow composite poles can be half or even less than that of solid wood poles. This not only reduces processing and transportation costs but also facilitates installation and transportation. In manufacturing composite poles, lumber from low-grade trees and recycled poles can be utilized. The disposal cost of solid poles can be greatly reduced by recycling into composite poles. Wood from plantation-grown trees, small diameter trees, short logs, crooked logs, and some processing residuals can be utilized as composite pole materials. For composite poles, preservative treatment is simple to be carried out. Checks often occur during the service period of a solid wood and if the check is deep enough to reach the untreated core, the check can provide entry for wood destroying insects and fungi that will shorten the usable service life of the pole. This situation is unlikely to happen to composite poles because of the size of the lumber and the permeability of plantation-grown wood (Tesoro and Choong 1976; Simpson et al. 1988). Moreover, the center is hollow in some designs.

It is believed that there is a potential market for this composite product. Utilization of low-grade timber bonded with high performance adhesives and fabricated using the optimal structural design will allow wood composite poles to have a great potential market and commercial values. This paper presents a summarization of previous known efforts to develop wood-based composite poles with special emphasis on the recent collaborative research between the Louisiana State University AgCenter, USDA Forest Service Southern Research Station, and Auburn University.

PREVIOUS STUDIES

Trees suitable for pole production must have long, straight, full-rounded boles with little taper. The trees that meet these requirements are from various species. Southern pine (*Pinus*, *sp*) is the main material for pole production in the nation. About 72 to 75 percent of poles are from this species (Koch 1972, Micklewright 1998). Other species for poles are Western red and Northern white cedars, Douglas-fir, chestnut, Atlantic white cedar, bald cypress, and redwood (Panshin et al. 1950).

In the last decades, many new approaches have been designed to solve the pole-resource-shortage problem. Marzouk et al. (1978) used four design schemes to make shorter solid wood poles longer by splicing or strapping two to four shorter poles using steel connectors. They presented three types of splicing and frame poles that are structurally suitable substitutes for wood distribution power poles. They also investigated the possibility of making composite poles from wood and concrete in which the top position was made of pine and bottom position was made of concrete.

The concept of composite poles appears in 1981, when Adams et al. (1981) fabricated an innovative product using wood flakes, synthetic resin, and preservatives, and termed it the COMPOLE. The COMPOLE series was 40-foot long hollow poles with square, hexagonal, or octagonal cross sections. This was the first time that the concept of a composite was applied in the field of wood poles. The poles they made were tapered from butt to tip according to the range found in solid wood poles. A computer program was used to design the poles and the optimal design they found was poles with a 7.5 cm (3 in.) wall thickness at a 33.8 cm (13.3 in.) ground-line diameter and an octagonal cross section. Shell thickness was reduced to 2.5 cm (1 in.) at the top.

Hollow poles have advantages over solid poles. Since the poles are hollow, the poles are lighter in weight, which will save the cost in materials, shipping and installation, compared with that of solid poles. From a mechanical analysis standpoint, when a pole is subjected to a bending test, the bending stress is highest on the surface layer and zero in the center part of the pole due to the effect of moment of inertia. Ninety percent of a pole's bending strength is attributable to 22 percent of its diameter on both sides of the cross-section (Erickson 1995). Thus, taking some material from the center part will not significantly affect the service strength of poles. A conventional inspection method for poles in service also involves drilling to determine the shell thickness. A distribution pole is designated a reject if the pole shell thickness is 5 cm (2 in) or less (Wilson 1994). Examples like this can be found with the competitors to solid wood poles. Most of poles made of steel, concrete, and fiberglass are hollow inside.

Mechanical properties and weathering properties are obviously the two important factors that determined the application potential of COMPOLE. Krueger et al. (1982) reported that the average bending strength and modulus of elasticity (MOE) of aligned composite wood materials bound with isocyanate resin was 110.8 (16.1 x 10^3 psi) and 16,250 MPa (2.36 x 10^6 psi, respectively, which are higher than those of typical solid southern pine wood. The weight of COMPOLEs, however, is 50 percent of the weight of solid wood poles of the same class and length (Adams et al. 1981).

Although weathering and biological attacks affect both COMPOLEs and solid wood poles, COMPOLEs are more vulnerable to these attacks. Since preservatives are added to flakes before hot pressing, the preservatives had a detrimental effect on the initial strength properties of the COMPOLEs. Test results showed that COMPOLEs lost some strength after weathering tests (Krueger et al. 1982). The COMPOLEs that contain inorganic salt-type preservatives had very high strength loss. They attributed the strength loss to the high temperatures used in the accelerated weathering test and predicted that the same results may not be seen in actual in-service weathering conditions. Wood composites are normally pressed at high temperature and humid environments. The built-in stress in the materials after pressed may release whenever it is possible. When COMPOLEs are in an in-service application environment, they will be subjected to constant changes in ambient relative humidity. The durability of COMPOLEs is a real concern.

Erickson (1994, 1995) proposed and patented a new design of composite poles. The hollow veneered pole (HVP) consists of a truncated strip cone with three or more overwraps of veneer layers (Figure 1). Number of strips (NOS) in the cone could be 8 or whatever is most appropriate for the manufacture of a given sized pole. Each strip can be made from either random or standardized lengths of lumber, and can be finger-jointed to pole length. The overwraps are made of high strength softwood species veneer. Veneer grain direction is parallel to the pole axis. The function of veneer layers is to improve the bending strength and protect the glued surfaces of adjacent strips from weather.

Since the strips in HVP are made from solid wood, it can be expected that HVP will have better mechanical properties and weathering ability than those of COMPOLE. Also the weight of HVP should be less than that of the same size of COMPOLE because the density of structural composite materials is always higher than the density of wood material. All these make HVP an improvement on COMPOLE.

More recent research (Shmulsky and Erickson 2001, Erickson and Shmulsky 2002a, 2002b,) found that low grade or underutilized species can be readily incorporated as part of the hollow section of the Erickson (1994, 1995) pole. This efficient use of material reduces the amount of wood fiber required for wood poles by nearly 50%. Polymer reinforcement can be readily incorporated to favorably enhance the bending strength properties. Mechanical strength testing results were not sufficient to meet the required loading requirements for commercial distribution pole application however with minimal refinement of design architecture and processing parameters, required bending strength is achievable. To achieve commercial viability a maximum bending moment of 76,800 pound-feet must be reached. As tested the full-scale composite poles achieved approximately 60 percent of this value. Full-pole-section pressure treatment with pentachlorophenol in oil was readily achieved. Pilot-scale equipment capable of producing full-scale product has been designed, assembled, tested, and proven.

The wrapped veneer is the vulnerable part of the HVP. In the three-dimensional configuration of wood, the strength of the tangential direction is substantially lower than that of the longitudinal direction. When

HVP swells due to the moisture changes in strips and veneer, the veneer-wrap could be checked and peeled off and lose its utility. Furthermore, the over-wrap involves a complicated process of joining and gluing, especially when the pole is tapered. It is reported that the cost of over-wraps accounts for more than 20 percent of the total cost (Erickson 1994).

The potential use of reinforced plastics (RP) for laminated transmission poles has also been studied (Adams and Mark 1968, Mark et al. 1968, Tang and Adams 1973, Tang 1977). In this design, a jacket of structural RP is bonded to the pole in the attack-susceptible areas and for a sufficient distance away to leave residual exposed wood in a state inhibitory to decay organisms. The jacketed area also served to increase the mechanical properties of the poles because it is placed where the bending moment is the highest. The RP jacket was 11 feet in length starting at a distance of 3 ft. from the pole end. The poles were 35 ft. long and about 8 in. butt diameter. The poles were tested as cantilever beams. The maximum variation of experimental flexural stresses as compared with the theoretical values is 15% or less than the percentage of variation of the elastic constants for the wood core in the specimens tested (Mark et al. 1968). In a study by Tang and Adams (1977), untreated full-size wood poles were laminated with a RP jacket over their entire 33 ft. length. Mean diameter at the fixed end was 7.9974 in. for RP poles and 7.8263 for non-RP poles. All poles tested with a full length RP jacket showed an increase (16-21%) in bending stiffness compared to poles with no jacket. The RP jacket was found to be 10 to 16 times harder than the wood core, which may prevent woodpecker attacks on the pole.

Forintek Corp., now known as FP Innovations, has also conducted research on wood-based composite poles. Hsu (1993) developed a tubular pole from laminated veneer. The pole was constructed from two or more equal length and transversely curved pole section which have been joined together along their longitudinal edges to form the pole. Walser in Forintek's Western lab developed a hollow pole made from blunted wedge shapes cut from LVL and pressed together in a specially built circular press (Walser et al. 1988, 1992). It was somewhat similar to the COMPOLE. However, it did not stand up well to pressure treating and would have to be treated earlier in the manufacturing process (Morris 2008).

By far the most commercially advanced composite pole technology is that of Laminated Wood Systems, Inc. (LWS) in Seward, NE. Their poles range from structures that have been in service for more than 40 years to relatively new applications (Figure 2). The poles installed in 1963 were designed and furnished by Weyerhaeuser Corp., which used the same technology and glue used by LWS today. Pole heights range from 50 ft. or less to 175 ft. The company has 1,000 laminated wood poles in Idaho that have been in service since 1963. That is two years prior to the installation of the first tubular steel pole. According to Reisdorf (2008), the glue-laminated technology is a better proven history as compared to tubular steel poles. The poles are pressure treated after being fabricated. Recycled treated wood is not used in the process. The poles do not contain a hollow core and as a result are heavier than hollow core poles.

More recently, the Louisiana State University AgCenter, Auburn University, and USDA Forest Service Southern Research Station have conducted collaborative research on the design and development of laminated hollow wood composite poles with a uniform diameter, as another potential alternative for solid wood poles currently used in power distribution and telecommunication lines (Piao 2003, Piao et al. 2004, 2005a, 2005b, 2006, 2007). The wood laminated composite poles developed were thick-walled members with a polygonal cross section (Figure 3). The hollow poles have adequate strength and stiffness properties but are lower in weight, when compared to solid wood poles. The advantages of these composite poles are that they can be (1) made from decommissioned poles, (2) may require no retreatment (3) can easily be integrated with a multiple product closed loop recycling system for decommissioned preservative-treated poles. These advantages make this hollow pole competitive with solid wood poles or poles from other materials for the same application purpose. The major disadvantages include undetermined economic feasibility and lack of actual in service data (e.g., strength, decay, and climbability).

A large amount of decommissioned treated wood annually flows into the waste stream and most is sent to landfills, posing a significant environmental and tort risk. Therefore, there is a need to recycle treated wood and the heavy metals in the preservative. This paper summarizes the past and current efforts of developing wood-based composite utility poles with an emphasis on recent collaborative efforts based at the Louisiana State University AgCenter. The omission of any wood-based composite pole research efforts is unintentional.

Laminated Composite Poles with Uniform Diameter

Wood laminated composite poles consist of trapezoid wood strips that are bonded with resorcinol phenol formaldehyde (RPF) resin. In a study by Piao et al. (2004), two sizes of poles were made and tested, i.e., reduced-size and full-size composite poles. The species was southern yellow pine (*Pinus. sp*). The length of the reduced-size poles was 1.22 m (4 ft.). The diameter of the poles was 7.6 cm (3 in.). Strip thickness levels were 1.0 cm (0.4 in.), 1.5 cm (0.6 in.), 2.0 cm (0.8 in.), and 2.5 cm (1.0 in.), each of which had 6, 9, and 12 strips. Thirty-six small-scale composite poles were made with three replications for each combination of NOS and strip thickness levels. The length of the full-size poles was 640 cm (20 ft.). Two levels of NOS (6 and 12) and three levels of strip thickness (1.9 cm (0.75 in.), 2.9 cm (1.125 in.), and 3.8 cm (1.5 in.)) were selected as variables for the full-size poles. Twelve full-size composite poles were made. Lumber was first planed to the specific thickness and then cut to strips with a target size on a table saw. The RPF glue was uniformly hand-spread onto the two side-surfaces at 310 g/m^2 (63.3 pcf). Poles were pressed in molds for 36 hours in an air-conditioned room.

A cantilever test was performed for all the composite poles using a RIEHLE machine. Before the test, the control system of the RIEHLE was replaced by a digital controller that was connected to a computer. All small-scale composite poles were tested to failure to obtain the maximum bending stress. The full-size poles were not loaded to failure due to a subsequent test on these poles. A load of about 350 N (80 lbs) was applied to each of the full-size composite poles to ensure that the test specimens were in the elastic range. The load-deflection curve was obtained for each full-size or small-scale pole after the bending test. These curves were used to obtain the deflection values.

Test results of the small-scale composite poles showed that the maximum bending stress of the composite poles was comparable to those of solid poles of the similar sizes. Both strip thickness and NOS were not correlated with the modulus of rupture (MOR) and modulus of elasticity (MOE) but did affect glue-line shear stress of the poles. The results also showed that shear failure was the major failure mode of the poles with thinner strip thickness. This is due to the fact that the removal of material from the pole center reduces the shear capacity of the composite poles. This work is helping to establish a new generation of composite poles with biomimicking features.

Laminated Composite Poles with Biomimicking Features

In order to minimize shear failure, measures for increasing the shear resistance of wood composite poles while still retaining the tube-type design for lightweight and structural performance were considered. Taper and node-like plywood webs for reinforcement were included in the new design of laminated hollow wood composite poles. In this regard, the concept of biomimicry of the bamboo nodal structure was incorporated within the design for the next generation of laminated hollow wood composite poles under consideration for this study (Piao et al. 2006). Biomimicry is a new discipline that studies nature's best ideas and then imitates these designs and processes to solve human problems.

It is well-known worldwide that bamboo is an excellent naturally occurring engineered material. Bamboo culms are lighter in weight than most building materials including solid wood. The structural characteristics of bamboo (i.e., high density, thin wall, nodal and hollow segments) give it superior mechanical properties for use as poles and beams as compared with the wood. For example, results from a study of Moso bamboo by Zeng et al. (1994) revealed that its mechanical properties, including modulus of rupture in static bending, compression strength parallel-to-grain, and shear strength, are much higher than those of longleaf pine (*Pinus palustris* Mill.) wood as reported in the USDA Wood Handbook (1999). Longleaf pine is recognized as the primary softwood species for manufacturing utility poles among the four major southern pine species (i.e., loblolly, longleaf, shortleaf, and slash) in the southern USA (Koch 1972).

Since nodes in bamboo culms increase the moment of inertia in the cross section, they have the function of increasing bamboo's load capacity, providing resistance to shear, reducing lateral buckling in bending and torsion buckling, and also improving bamboo's structural integrity. Thus, the characteristics of nodal structure in bamboo was bio-mimicked in the design of laminated tapered and hollow wood composite poles for increasing their shear resistance, lateral stability in bending, and torsional stability.

Five taper and hollow composite poles were made for this study. Four of these composite poles, designated as Pole-A, -B, -D, and –E, had a hollow structure and were fabricated with 9 equal-dimension trapezoid southern yellow pine (SYP) strips. Pole-A and Pole-B had a round cross-section and they were machined on a lathe to a taper of 0.3°. Pole-D and Pole-E had a 9-side polygonal cross-section with a uniform diameter (i.e., no taper) through the entire length. The 5th member was a solid pole with a taper of 0.3°. It was made by first face-to-face gluing four pieces of 3.81 cm by 10.2 cm (1.5 in. x 4 in.) SYP lumber and then circularly shaving into a tapered pole using a lathe. The node-like plywood-webs were only placed in Pole-A and –D and at intervals of 61 cm (2 ft.).

All fabricated poles were 2.44 m (8 ft.) in length and 10.2 cm (4 in.) in circumscribed diameter, which were slightly larger than those tested in the previous study (i.e., 1.22 m (4 ft.) in length and 7.6 cm (3 in.) in diameter) (Piao et al. 2004). The node-like webs were made from a 5.72-cm (2.25 in.) thick composite board which was fabricated with two sheets of 2.86-cm (1.126 in.) thick, 30-cm (11.8 in.) square 7-ply southern pine plywood by applying resorcinol phenol formaldehyde (RPF) resin. The outside diameter as well as the shape of these 5.72-cm (2.25 in.) thick node-like webs was carefully monitored to ensure that a tight adhesive-bond between them and the inner wall of the hollow members can be produced. The reason for using plywood as the web materials is because SYP plywood has more uniform and less in-plane swelling than solid SYP wood. Before the pole fabrication, all edges of the plywood-webs were wrapped with four layers of Kraft paper which was impregnated with RPF resin. These RPF resin impregnated paper layers may work as fasteners for the plywood-webs and the pole shell so that a strong bond between them can be achieved. It may also seal the air chamber between any two webs to slow down the moisture flow in the hollow poles and prevent the humid moisture from underground from going to the upper part of the pole. This was done as a simulation of bamboo diaphragms, which completely seal the chamber of a bamboo culm. The paper wrapped plywood-webs were placed inside the pole at intervals of 61 cm (2 ft.) along its length axis and in both ends of each member.

Test results showed that all poles in the cantilever bending test exhibited extreme fiber failure, which was always accompanied by long and deep springwood failure along the wood grain of the failed strips. The tapered hollow poles showed a longer failure zone than the non-tapered members. The webs in the hollow poles reduced the propagation of wood failure along the pole length axis and increased the static bending properties on a per weight basis. The results also showed that the webs reduced the local shear stress. This suggests that the node-like webs reinforce the shear capacity of the poles.

Theoretical Modeling of Composite Poles with Uniform Diameters

A high-order governing differential equation (GDE) model was developed to assess and predict the performance of the wood laminated composite poles based on the principle of minimum potential energy. Transverse shear and glue-line effects were taken into account in the development of the model. A simplified theoretical model was also derived to work as a comparison with the high-order GDE model. The theoretical model developed is as follows:

$$w = C_1 + C_2 x + C_3 x^2 + C_4 x^3 + \frac{1}{48k_8} p_0 x^4 + C_5 e^{k_{10}x} + C_6 e^{-k_{10}x}$$

where k_1 to k_{10} are functions of the pole cross sections and C_1 – C_6 are constants and are given as

$$C_1 = \frac{k_{10}(p_0 L + P)(e^{k_{10}L} - e^{-k_{10}L}) + 2p_0}{2k_8 k_{10}^4 (e^{k_{10}L} + e^{-k_{10}L})}$$

$$C_2 = -\frac{p_0 L + P}{2k_8 k_{10}^2}$$

$$C_3 = \frac{p_0 L^2 + 2PL}{8k_8} + \frac{p_0}{2k_8 k_{10}^2}$$

$$C_4 = -\frac{p_0 L + P}{12k_8}$$

$$C_5 = \frac{k_{10}(p_0 L + P)e^{-k_{15}L} - p_0}{2k_8 k_{10}^4 (e^{k_{10}L} + e^{-k_{10}L})}$$

$$C_6 = -\frac{k_{10}(p_0 L + P)e^{-k_{15}L} + p_0}{2k_8 k_{10}^4 (e^{k_{10}L} + e^{-k_{10}L})}$$

where P is the concentrated load applied on the free end of the pole, p_0 is the body force of the pole, and L is the pole length.

Results showed that the high-order differential equation model correlated well with the experimental results as well as with the simplified model. The simplified model was more accurate than the high-order GDE model in predicting the deflection of the composite poles, but the high-order GDE model was more suitable for analyzing complex pole geometries.

Finite Element Analyses of Composite Poles

To further analyze the performance and design the laminated composite poles, finite element models were developed for laminated composite poles with a uniform diameter (Piao et al. 2005a) and biomimicking features (Piao et al. 2007). The analytical procedure involved parametrically modeling the deflection and normal and shear stress of five composite poles with biomimicry features with ANSYS, commercial finite element modeling software developed by ANSYS, Inc. Both hollow and solid composite poles were analyzed as orthotropic materials. In the modeling of composite poles with uniform diameters, the composite poles were viewed as glued volumes of trapezoid wood strips and the effect of the glue lines were neglected. In the modeling of composite poles with biomimicking features, each hollow composite pole was viewed as a glued volume composition of trapezoid wood strips, rectangular prism gluelines and/or polygonal node-like webs. A tetrahedral element type with 10 nodes each having three degrees of freedom was assigned to each member of both uniform-diameter and biomimicking composite poles. This element type has a nonlinear displacement behavior, plasticity, large deflection, and large strain capabilities.

The Young's moduli in the analyses of both uniform diameter and biomimicking composite poles were obtained from the corresponding experiments. In the biomimicking model, the plywood node-like webs and RPF impregnated Kraft papers wrapped outside the webs were treated as one material. In the modeling, the constitutive properties of these webs were approximated by the constitutive properties of the plywood used. Other constitutive properties of wood and all constitutive properties of nodal materials (plywood) in the models were obtained from the Wood Handbook (USDA FPL 1999). Constitutive properties of RPF resin were obtained from the Adhesive Handbook (Shidles 1970). Wood strips and plywood node-like webs were assumed to be orthotropic materials, while glue lines were assumed to be an isotropic material. It is well known that the interface between wood and RPF is a complex matrix and was simplified in this analysis as two clean volumes that were glued together.

The deflection and stress of each pole under a concentrated load at its free end were modeled for both types of the poles. The size parameters of each pole were constant and equal to the corresponding pole that the model simulated. The deflection and normal stress along each pole were determined by retrieving the deflection and stress values of the nodes on the top surface of the pole. The shear stress under each load was determined by the shear stress of the nodes on one side of the pole surface in the neutral plane. These shear values may not be the maximum under a specific load level but will display the shear variation along the pole. Deflection and normal stress values were compared to the corresponding deflection and stress obtained from the experiment.

The predicted deflection by both the uniform-diameter and biomimicking models agreed well with those from the experiments. Predicted normal stress also agreed with those calculated. In the modeling of biomimicking poles, the normal and shear stress distributions inside the members were investigated and stress distribution in XY and YZ planes were exhibited. As expected, the node-like webs reduced the local shear stress and improved the shear capacity, especially on the pole top and in clamped line regions where shear levels were the highest, but had little effect on the bending stress. The shear stress increased from the bottom to the top for the members with taper. Large shear stress concentration was predicted in a small region around the clamped lines. The models also predicted the shear stress of the tapered hollow poles decreased from the inside to the outside surfaces in a cross section in the XY plane. Gluelines were the weak regions which were likely subjected to shear failure.

Future Studies of Laminated Composite Poles

Modeling of Composite Poles with Biomimicking Features

Future research will be conducted to determine the exact solution of tapered composite poles with biomimicking features. This requires the development of a theoretical model for tapered composite poles based on the theoretical model developed for the composite poles with uniform diameters. Taper, node-like webs, shell wall thickness, and gluelines have already been investigated in finite element analyses of composite poles with biomimicking features. However, their effects on the performance of composite poles are unknown and need further study. This will be done with the optimization analyses of the composite poles with ANSYS.

Laminated Composite Poles from Decommissioned Preservative-Treated Wood

An economically feasible and environmentally friendly method of recycling decommissioned wood poles is needed. The existing methods of wood pole recycling are inadequate and do not adequately satisfy these criteria. In a closed loop recycling system, the decommissioned preservative-treated wood can be used as the raw material for engineered wood products such as laminated composite poles.

In making the composite poles, the sound portions of the poles will be sawn into trapezoid wood strips. The preservative-treated wood strips can then be finger-jointed and assembled into wood laminated composite poles. Strips from untreated wood may be combined with the preservative-treated wood strips in composing the poles to reinforce the strength of the composite poles.

In the development of composite poles using decommissioned preservative-treated wood, resin impregnation and surface densification technologies will be used to reinforce the composite poles from decommissioned preservative-treated wood. In resin impregnation, the surfaces of wood strips of both treated wood and fresh wood will be impregnated with synthetic resins such as phenol-formaldehyde (PF) and isocyanate resins. The surfaces with resins will then be densified by compression under heat. These treatments will reinforce the strength properties, especially the MOE of the composite poles. Resin types, impregnating time, and compressive pressure will be evaluated to determine the effects of these variables on the mechanical properties of the composite poles.

Finite element models will be developed to assess the properties and optimize the design of the composite poles from decommissioned preservative-treated wood as well as from fresh wood.

Field Testing of the Composite Poles

In-field durability tests of wood composite poles made from both untreated wood and decommissioned preservative-treated wood will be conducted at the Louisiana State University Agricultural Center, Calhoun Research Station at Calhoun, La. A distribution system with a number of composite poles, composite cross arms, and overhead cables will be installed in the field. Force gauges will be installed in each of the cables and strain gauges will be attached on the surfaces of each of the composite poles. The Young's modulus of each composite pole will be calculated based on the measured force and strain and will be monitored by a computer for at least 10 years. The durability and degradation process of the composite poles will be determined by evaluating the Young's modulus of the poles over time. A conventional distribution system with solid wood poles will be also installed next to the composite poles system to work as a control for the composite pole study.

CONCLUSIONS

Wood laminated composite poles are a promising alternative to the solid wood poles that are widely used in the power transmission and telecommunication fields. Composite poles with biomimicking features such as taper, nodes, and surface densification are light, easily treated with preservatives, and have comparable strength to solid wood poles. The raw materials for the composite poles can be low-valued wood such as small diameter logs and decommissioned preservative-treated wood. In addition to poles, cross arms and other engineered wood products can be made from low-valued timber and decommissioned treated wood. The theoretical and finite element models developed from these and future studies will be indispensable tools for the property assessment, design, manufacture, installation, and maintenance of composite poles. These studies can potentially pave the way for utilization of wood laminated composite poles from decommissioned treated wood for the power transmission and telecommunication fields.

REFERENCES

1. Adams, S.F. and R.E. Mark. 1968. Composite pole laminates for transmission supports. In: Proceedings of the 4th Wood Pole Institute. Colorado State Univ. Fort Collins, Co.
2. Adams, R.D., G.P. Krueger, S. Long, A.E. Lund, D.D. Nicholas. 1981. CompoleTM – the composite wood material utility pole. American Wood-Preservers' Association 77:81-88.
3. American Wood Preservers Institute (AWPI). 1996. Life-cycle costs of four types of poles. www.awpi.com. Accessed 06/12/96.
4. Canadian Institute of Treated Wood (CITW). 1998. Pole talk. Web address: www.citw.org/poletalk
5. Erickson, R. W. 1994. The hollowed veneered pole. In: Pacific Timber Engineering Conference. July 11–15, 1994. Gold Coast, Australia.
6. Erickson, R.W. 1995. Hollow veneered pole. U.S. Patent. Number 5,438,812.
7. Erickson, R.W. and R. Shmulsky. 2002a. Small diameter trees into advanced round composites. Comm. & Econ. Development Opportunities in Small Tree Utilization. Albuquerque, NM.
8. Erickson, R. and R. Shmulsky. 2002b. The hollow veneered pole: "Guess who's not coming to dinner." In: Enhancing the durability of lumber and engineered wood products conf. Orlando, FL.
9. Hsu, W.-H.E. 1993. Laminated veneer round pole. Canada Patent Office. Canadian patent 1,325,096.
10. Koch, P. 1972. Utilization of the southern pines, Vol. 1, USDA For. Ser. Exp. Sta., Agric. Handbook 420, Washington DC. 1663 p.
11. Krueger, G.P., L.B. Sandberg, R.D. Adams. 1982. Applications of the IWR composite wood material. American Society of Civil Engineers, April 26-30, 1982. Las Vegas, NV.
12. Mark, R.E., S.F. Adams, and M. Maiti. 1968. Design of a composite pole laminate. Forest Prod. J. 18(4):23-28.
13. Marzouk, H. M., M. U. Hosain, and V. V. Neis. 1978. Built-up utility poles using prairie timber. Forest Prod. J. 28(11):49-54.
14. Micklewright, J.T. 1998. Wood preservation statistics 1997. American Wood-Preservers' Association. Granbury, TX. 22 p.
15. Miller, D. J. and R. D. Graham. 1970. Durability of Douglas-fir hop poles treated with preservatives by diffusion. Forest Prod. J. 20(6):43-44.
16. Morris, P. Personal communication with T. Shupe on 5/14/08.
17. Panshin, A.J., E.S. Harrar, W.J. Baker, P.B. Proctor. 1950. Forest products: their sources, production, and utilization. McGraw-Hill Book Co., Inc.
18. Piao, C. 2003. Wood laminated composite poles. Ph.D. Dissertation. Louisiana State University. Baton Rouge, La. 108 p.
19. Piao, C., T.F. Shupe, and C.Y. Hse. 2004. Mechanical properties of small-scale wood laminated composite poles. Wood Fiber Sci. 36(4):536-546.
20. Piao, C., T.F. Shupe, R.C. Tang, and C.Y. Hse. 2005a. Finite element analyses of wood laminated composite poles. Wood Fiber Sci. 37(3):535-541.
21. Piao, C., T.F. Shupe, V.J. Gopu, and C.Y. Hse. 2005b. Theoretical modeling and experimental analyses of laminated wood composite poles. Wood Fiber Sci. 37(4):662-672.

22. Piao, C., T.F. Shupe, R.C. Tang, and C.Y. Hse. 2006. Mechanical properties of small-scale laminated wood composite poles: Effects of taper and webs. Wood Fiber Sci. 38(4):633-643.
23. Piao, C., T.F. Shupe, C.Y. Hse, and R.C. Tang. 2007. Finite element analysis of tapered wood laminated composite poles with biomimicking features and gluelines. In: (H.M. Barnes, ed.) Proceedings Southeastern Utility Pole Conference. Southern Forest Products Association. Madison, WI. ISBN 1-892529-43-2. p. 233.
24. Reisdorf, B. Personal communication with T. Shupe 03/03/08.
25. J.B. 1970. Adhesive Handbook. CRC Press, A Division of the Chemical Rubber Co., Cleveland, OH.
26. Shmulsky, R. and R.W. Erickson. 2001. Engineered hollow wood composite poles. In: 2nd International Conf. on Advanced Engineered Wood Composites. Bethel, ME. Aug. 14-16, 2001. pp. 1-4.
27. Simpson, W.T., J.D. Danielson, and R.S. Boone. 1988. Press-drying plantation-grown loblolly pine 2 by 4's to reduce warp. Forest Prod. J. 38(11/12):41-48.
28. Tang, R.C. and S.F. Adams. 1973. Applications of reinforced plastics for laminated transmission poles. For. Prod. Journal, 23(10):42-46.
29. Tang, R.C. 1977. Environmental effects on transmission poles laminated with reinforced plastics. In: Proceedings of Conference of Environmental Degradation of Engineering Materials. pp. 403-424.
30. Tesoro, F.O. and E.T. Choong. 1976. Relationship of longitudinal permeability to
31. treatability of wood. Holzforshung 30(3):91-96.
32. USDA-FS-FPL. 1999. Wood Handbook: Wood as an engineering material. Forest Products Society and Forest Products Laboratory. Madison, WI.
33. USDA-FS-FPL. 2008. NewsLine. Spring, 2008. Forest Products Laboratory. Madison, WI. Vol. 7, Issue 2, p. 6.
34. Walser, D.C., N.R. Walser, and P.R. Tarasoff. 1988. Technical evaluation for developing plywood utility poles. Canadian Electrical Association. 211 D 516. Report : 1v. [W-711] Contract no.: 1891L652. Ottawa, ON
35. Walser, D.C., C. Lum, and G.E. Troughton. 1992. Evaluation of plywood utility poles. Canadian Electrical Association. Contract Report : (CEA No. 211 D 516A) [W-968]. Ottawa, ON.
36. 74 p.
37. Wilson, J. B. 1994. NDE: Tools for the future. In: Proc. Southeastern pole conference (Barnes, H.M.; Amburgey, T.L., eds). Nov. 8-11, 1992, Mississippi State University, Starkville, MS, Proceedings 7314, Forest Products Society, Madison, WI, p. 26-37.
38. Zeng, Q., S. Li, and X. Bao. 1992. Effect of bamboo nodes on mechanical properties of bamboo. Scienta Silvae Sinicae. 28(3): 247-252.

Figure 1. Cross section of the veneer wrapped composite strip pole developed by Erickson at the University of Minnesota. (Photo courtesy Dr. Rubin Shmulsky).

Figure 2. Laminated wood utility pole made by Laminated Wood Systems, Inc. in the U.S. (Photo courtesy of Bob Reisdorff).

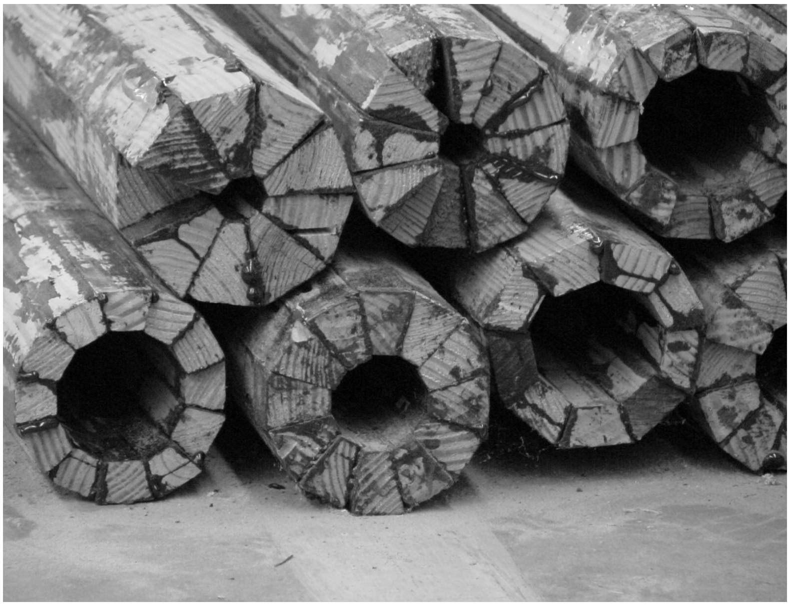

Figure 3. A sampling of different configurations of wood strip composite poles fabricated by Piao and coworkers at Louisiana State University AgCenter.