Optimization Analysis of Tapered Wood Laminated Composite Poles with Biomimicking Features

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ABSTRACT

Five finite element models were developed with ANSYS to predict and assess the performance of five types of composite members: a tapered hollow pole with node-like plywood webs (Pole-A), a tapered hollow pole without node-like webs (Pole-B), a tapered solid composite pole (Pole-C), a uniform-diameter hollow pole with node-like webs (Pole-D), and a uniform-diameter hollow pole without node-like webs (Pole-E). Based on these models, a preliminary optimization analysis was conducted by evaluating the effects of taper angles, strip thickness, and web length on the deflection of composite poles. It was found that linear relationship existed between taper angles and deflection of the poles. Pole deflection curvilinearly decreased with an increase of strip thickness. The length of the node-like webs had more of an effect on the deflection of the poles that had thinner strips.

Keywords: optimization, finite element analysis, tapered pole, biomimick, poles, laminated composites

INTRODUCTION

Wood laminated composite poles with biomimicking features are a new generation of wood laminated composite poles that were developed as an alternative to solid wood poles used in power transmission and telecommunication. They are hollow tapered poles and composed of trapezoid wood strips and node-like webs, which were consolidated by resorcinol phenol formaldehyde (RPF) resin. The taper and node-like web structures were biomimicked or copied from the structural features of bamboo. Node-like webs reduced local shear stress (Piao et al. 2006, 2007), lateral bucking and moisture movement in the poles. The web structure is an important structural feature in the design of future wood laminated composite poles. Therefore, it is necessary to further analyze and design the webs and other biomimicking features to maximize the performance of the composite poles.

This study is part of a bigger study on the optimization analysis of composite poles with biomimicking features. The objective of the bigger study was to further improve the mechanical and durability performance of the composite poles for utility application. Taper angles, wood strip thickness, web length and distribution, finger-joint styles and distribution, surface densification and resin impregnation are some of the treatments that were and will be used for the optimization analysis. The objective of this study was to maximize the performance of composite poles through taper angles, strip thickness, and node-like webs. This paper presents some preliminary results of this study.

ANALYTICAL PROCEDURES

The analytical procedure is similar to that in a previous study of finite element analysis of tapered composite poles with biomimicking features (Piao et al. 2007) and is briefly summarized as follows. In the modeling, both hollow and solid composite poles were analyzed as orthotropic materials. 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. This element type has a nonlinear displacement behavior, plasticity, large deflection, and large strain capabilities. The graphical representations of the poles were formed by a series of Boolean operations with ANSYS. Then wood strips, glue lines, and/node-like webs were glued to create a pole model for each of the five members. The volumes in each member were meshed separately. The Young's moduli of the poles in the z (height) direction were the modulus of elasticity (MOE) values obtained from a pervious experimental study (Piao et al. 2006). The constitutive properties of the webs were approximated by the constitutive properties of the plywood used. Other constitutive properties of wood and all constitutive properties of nodal materials (plywood) were obtained from the Wood Handbook (USDA FPL 1999). Constitutive properties of RPF resin were obtained from the Adhesive Handbook (Shidles 1970). Table 1 lists the constitutive properties of wood, plywood, and glue lines. 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 resin is a complex matrix. The interface was simplified in this study as two clean volumes that were glued together.

The deflection of each pole under a concentrated load at its free end was modeled. Table 2 lists the shape specifications of the poles, gluelines, and node-like webs used in this modeling. Three variables were selected for this preliminary study. They were taper angles (0.1 to 0.35^{o}), strip thickness (20 to 30 mm), and node-like web length (7.6 mm to 240 mm).

RESULTS AND DISCUSSION

In formulating (Boolean operations) and/or meshing the gluelines with ANSYS, program failures occurred to some physical dimensions and glueline element sizes. Similar problems occurred in the previous study (Piao et al. 2007). This shows the limitation of ANSYS in modeling members with some difficult geometries. When such a case occurred, alternative line divisions or element sizes were used. The modeling was conducted in a desktop computer with a Pentium® III processor. The total number of equations was from 110 thousands to 200 thousands for the five models. The average computer running time for each model was about 1.5 hours. Fig. 1 shows parts of the meshing of the tapered pole with node-like webs (Pole-A). The element size for the gluelines was 14 mm, which was the maximum executable element size for such a large length-to-thickness ratio in ANSYS for this modeling. The element sizes for wood strips and node-like webs were 25 mm and 16 mm, respectively. The meshed volumes shown in the middle of Fig. 1 include a glueline on the top, 4 node-like webs in the middle, and one wood strip on the bottom. The meshing of other gluelines and wood strips is similar to those in the figure and as such is not shown. The top section and the cross section at the clamped line are highlighted in square frames to give a clear demonstration of the meshing.

Previous results showed that the shear stress of taper poles increased from the bottom to the top of the poles, but the shear stress leveled along the poles without taper (Piao et al. 2007). Therefore, taper angles had effects on the shear stress and deflection of the poles. Fig. 2 shows the predicted variation of pole deflection as taper angles increased from 0.1^{o} to 0.35^{o}. Regression results indicated that a linear relationship existed between taper angles and deflection and was predicted by the model. Increasing taper angles of the poles may lead to a linear increase of pole deflection. These models also predicted that the linear relationship between taper angles and deflection is affected by web length inside the poles. The solid pole can be viewed as a hollow pole that had web length equal to the length of the pole. No significant trend was found for the effects of web length on the regression slopes. However, these models predicted that the solid wood composite pole had the lowest slope value among the three kinds of poles.

Figs. 3 and 4 show the predicted effects of strip thickness and web length on the deflection of composite poles. Curvilinear and linear relationships were predicted by these models between strip thickness and deflection and between web length and deflection, respectively. Strip thickness may have more effects on the deflection when the thickness was less than 24 mm (about 1 inch) for a pole that had a diameter of 152.4 mm (6 inches). Therefore, the strip thickness should be greater than 1 inch for a 6-inch-diameter pole. This indicates that the model developed in this study can be used to find the minimum strip thickness for a pole with a particular dimension. The models also predicted that web length had very limited effects on the deflection of composite poles. Web length had more effects on deflection when composite poles had a thinner strip thickness. Evaluation of web length on shear stress will be conducted in the next study.

It is noted that the results presented this paper were predicted by finite element models developed in this study. Previous studies had shown that good agreement was found between finite element models and experimental results on wood laminated composite poles. However, the data from modeling needs verifications before it can be applied in practical applications. The experimental verification of the results will be conducted in our next study.

SUMMARY AND CONCLUSIONS

Optimization analyses were conducted by evaluating the effects of taper angles, strip thickness, and node-like web length on the deflection of tapered wood laminated composite poles with node-like webs. The preliminary results showed that all three variables had effects on the deflection of composite poles in a cantilever bending test scenario. Linear relationships were predicted by the models between taper angles and deflection and between web length and deflection. A curvilinear relationship was predicted between strip thickness and the deflection of the composite poles. The models can be used to predict the minimum strip thickness for a composite pole. Experimental study will be conducted next to verify the results obtained by this finite element modeling.

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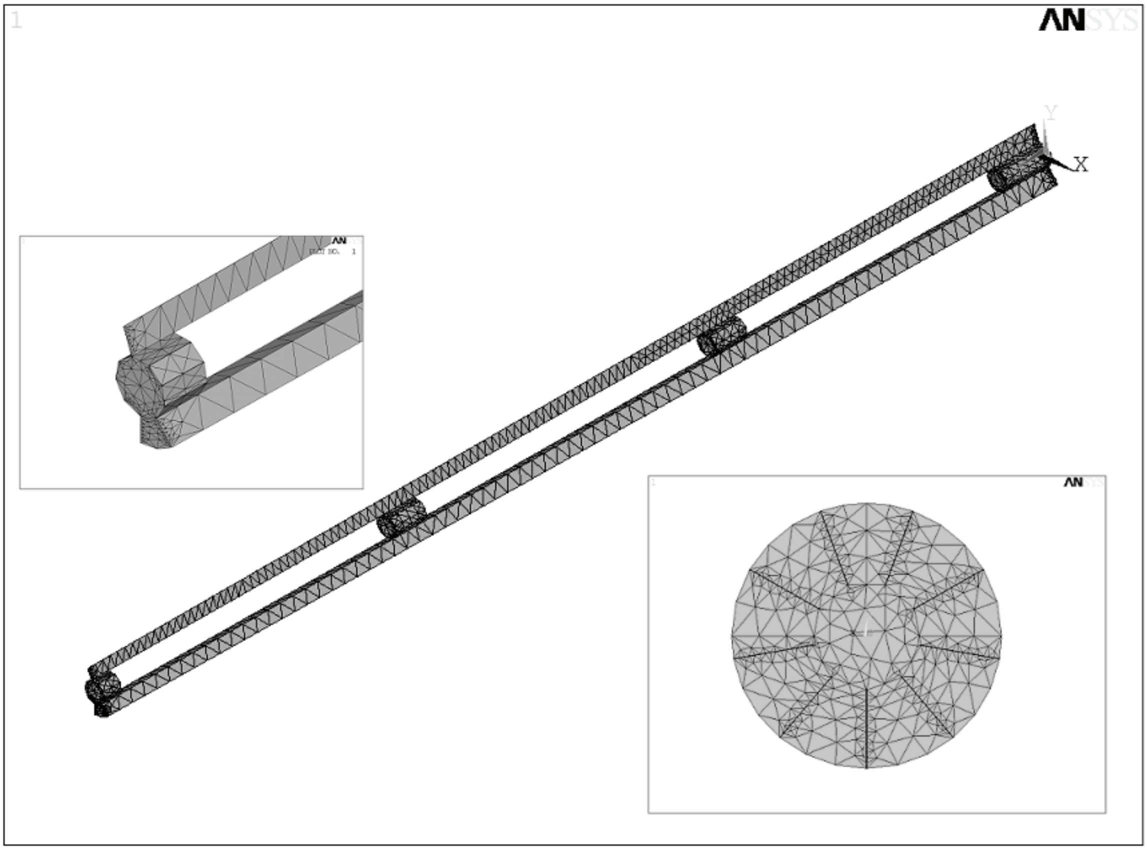

Fig.1. The meshing of gluelines, wood strips, and node-like webs in the modeling of a tapered wood laminated composite pole with node-like webs.

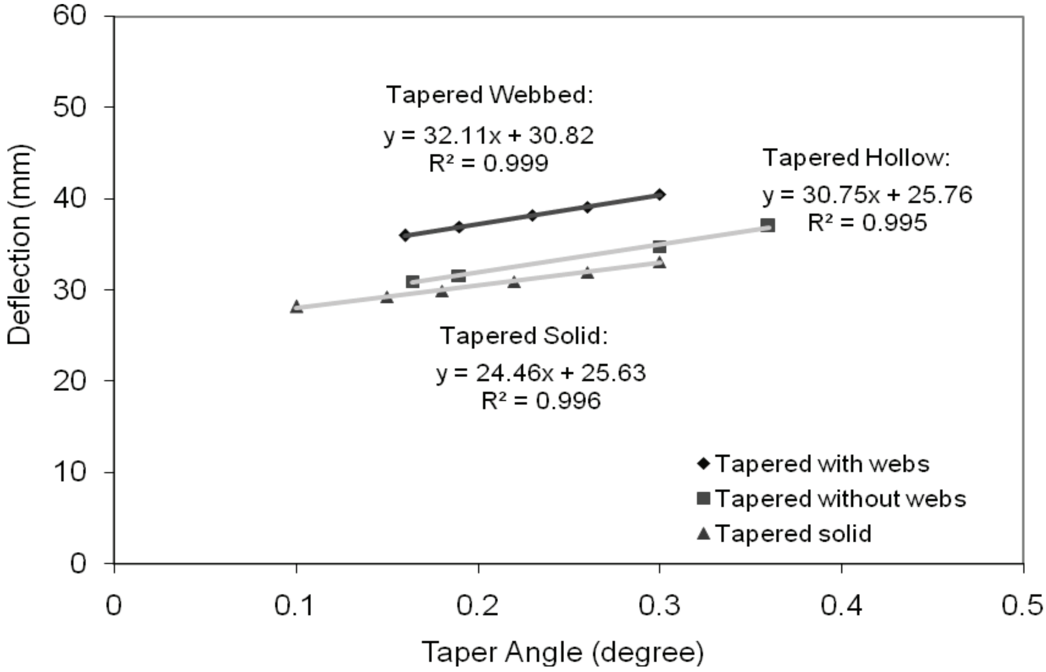

Fig. 2. Predicted effects of taper angles on the deflection of wood laminated composite poles subjected to a cantilever bending test.

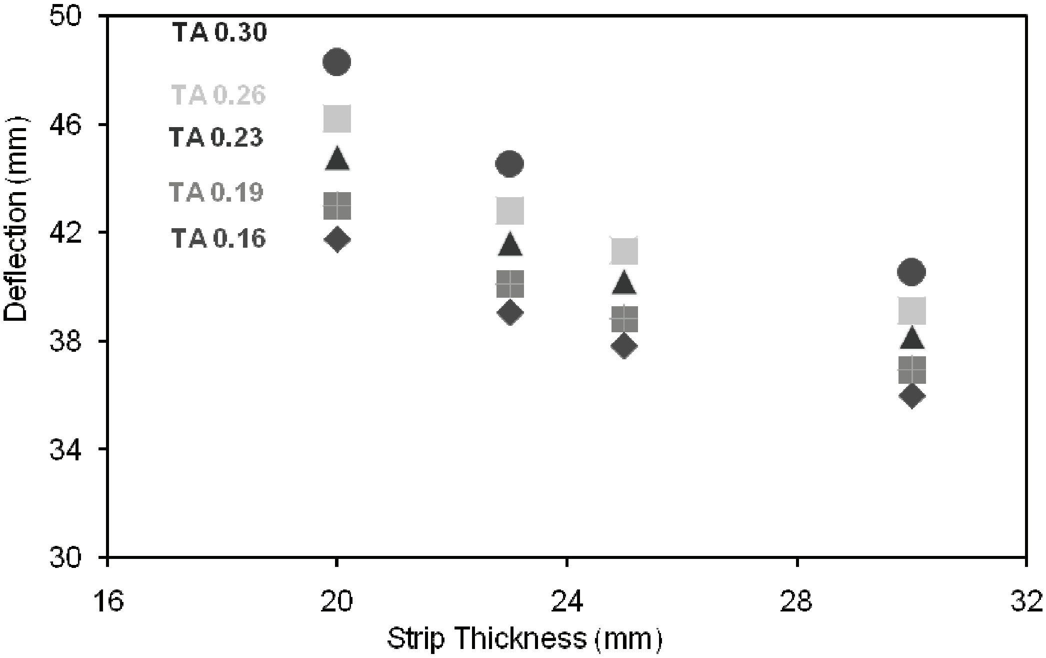

Fig. 3. Effects of strip thickness on the deflection of wood laminated composite poles subjected to a cantilever bending test.

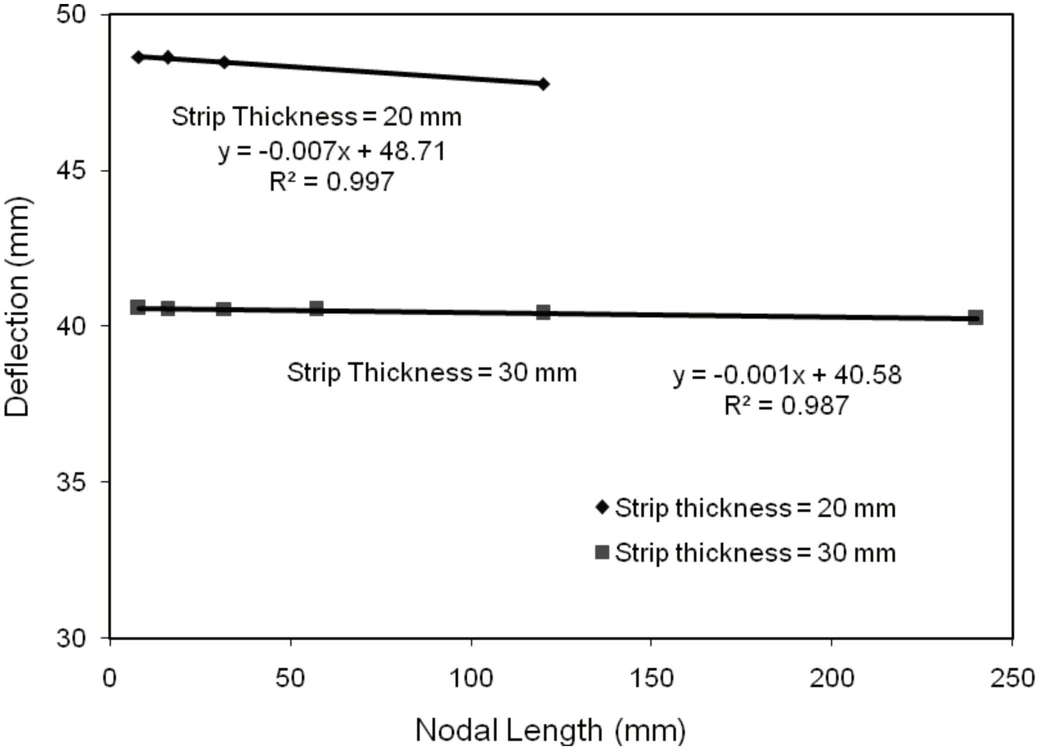

Fig. 4. Effects of web length on the deflection of wood composite poles subjected to a cantilever bending test.

Table 1. Constitutive properties of wood[1], resorcinol phenol formaldehyde (RPF) resin[2], and plywood[3].

Pole Types	E_x (10^3MPa)	E_y (10^3MPa)	E_z (10^3MPa)	G_{xy} (MPa)	G_{yz} (MPa)	G_{xz} (MPa)	ν_{xy}	ν_{yz}	ν_{xz}
A	1.2	1.2	11.5	149.7	938.3	938.3	0.38	0.30	0.30
B	1.2	1.2	11.4	149.7	938.3	938.3	0.38	0.30	0.30
C	1.2	1.2	12.6	149.7	938.3	938.3	0.38	0.30	0.30
D	1.2	1.2	10.1	149.7	938.3	938.3	0.38	0.30	0.30
E	1.2	1.2	8.1	149.7	938.3	938.3	0.38	0.30	0.30
RPF	4.5	4.5	4.5	500.0	500.0	500.0	0.20	0.20	0.20
Plywood	12.5	10.8	1.3	938.3	150.0	150.0	0.15	0.14	0.14

[1] Southern yellow pine (*Pinus* sp). USDA FPL (1999).
[2] Adhesive Handbook (Shidles 1970).
[3] Wood Handbook (USDA FPL 1999).

Table 2. Specifications of wood laminated composite poles in the finite element modeling.

Species	Pole length (mm)	Pole diameter (mm)	Glueline thickness (mm)
SYP	1828.8	101.6	0.2032