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Study of timber crossarms coated with castor oil-based polyurethane resins: electrical and mechanical tests

R. A.C. Altafim[1] J.F.R. Silva[2] H.C. Basso[1] C. Calil Júnior[1] J.C. Sartori[1] C.R. Murakami[1]
R.A.P.Altafim[1] G.O. Chierice[3] A.Silveira[2]
[1] São Carlos School of Engineering, University of São Paulo, SP, Brazil
[2] Elektro Eletricidade e Serviços S.A., Campinas, SP, Brazil
[3] São Carlos Institute of Chemistry, University of São Paulo, SP, Brazil
C. Postal 359 - CEP 13566-590 - São Carlos, SP, Brazil
e-mail: altafim@sel.eesc.sc.usp.br

***Abstract*: While many countries, including Norway, have long used laminated wood to great advantage as an alternative material for transmission and distribution line supports, the traditional crossarms made of native wood species are still commonly employed in Brazil. This continued use of wood is attributed mainly to its low cost compared with other elements of the power supply system. However, environmental considerations and the shorter lifetime of wood have changed this situation, intensifying the research in this area. This paper discusses two reforested wood species, Slash Pine *(Pinus elliottii)* and Lemon Eucalyptus *(Eucalyptus citriodora)*, coated with castor oil-based polyurethane resins, as an alternative material for distribution line crossarms, from the standpoint of their mechanical and electrical properties and their low cost. A complete description is also given of the entire coating process.**

INTRODUCTION

Brazil's vast territory and its huge forested regions have collaborated in the intensive use of traditional crossarms made of native wood species in distribution lines. However, this situation is changing due to the increasingly high cost of native species and Brazil's new environmental laws [1]. In this context, electric power utilities have been seeking alternatives, one of which is laminated wood, which has long been used as a material for electric power transmission and distribution structures in many countries. Norway, for example, has been using laminated woods for over twenty years, first for cross-arms in distribution lines and later for complete 66 and 134 kV transmission line structures [2]. In the early 1990s in the US, Union Electric (UE) also evaluated alternatives for solid wood products, whose prices have increased steadily over the last decade, particularly those of crossarms. UE has found that laminated wood crossarms can offer an economically feasible alternative at costs equal to or lower than solid sawn crossarms [3]. Although laminated wood is also a viable alternative for Brazilian utilities, reforested *Pinus Elliotti* and *Eucalyptus citriodora,* which satisfy the strength requirements for solid sawn crossarms [4], can be used provided they are subjected to special surface treatment.

This paper presents and discusses the use of crossarms made of these two species and coated with a castor oil-based polyurethane resin – *Ricinus communis* [5]. Mechanical and electrical tests have confirmed that crossarms made of these species can be both economically competitive and ecologically acceptable.

EXPERIMENTAL PROCEDURES

All the samples used in this research were made of the reforested species *Eucalyptus citriodora* and *Pinus elliottii* whose average rigidity and strength values are listed in Table I, which also shows other native woods used for crossarms.

Table I
Average values of rigidity and strength [4]

Species	ρ_{ap} (1) kg/m^3	E (2) MPa	F_n (3) MPa
Eucalyptus citriodora	999	18421	3.9
Pinus elliottii	640	12813	2.6
Hymenaea spp	1074	23607	3.2
Manilkara spp	1143	22733	5.4
Tabebuia serratifolia	1068	18011	3.1

(1) ρ_{ap} = apparent specific mass at 12% of humidity
(2) E = elasticity modulus
(3) F_n = normal fiber tensile strength

Resin coating process

Figure 1 shows the vacuum mixer especially developed for this research. The wood samples for all the tests were dried at room temperature and coated with resin without filler.

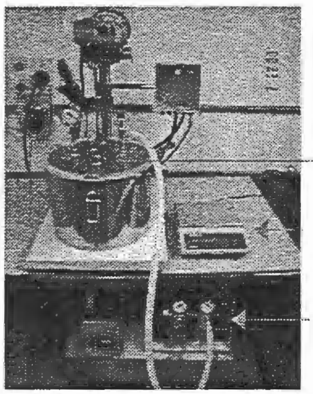

Figure 1 - Polyurethane Resin Vacuum Mixer.

The resin, dubbed RI 3, was prepared by weighing the polyol on a semi-analytic scale, to which the pre-polymer was added in a mass proportion of 1:1.5.

These two components were mixed for about 3 min in a vacuum below 100 mbar to extract air bubbles.

A uniform, 0.2 mm thick layer of resin was applied with a brush on the wood surface at room temperature (25°C). The samples were allowed to rest for 24 hours for the resin to cure.

Electrical tests

The electrical tests for surface resistivity, ρ_s, and dielectric dissipation factor, tan δ, were carried out on 50 x 120 x 6 mm resin-coated samples of *Eucalyptus citriodora* impregnated with oil (CT), non-impregnated *Eucalipytus Citriodora* (CN), and non-impregnated *Pinus elliottii* (PN). These tests, each of which involved five samples, was conducted according to the ASTM standards [6,7,8]. Figure 2 shows the oil-impregnated samples.

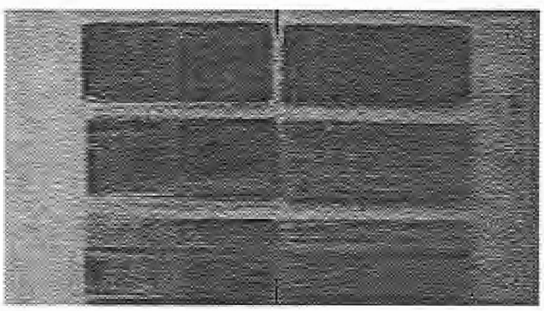

Figure 2 – Wood samples coated with polyurethane resin

Similarly prepared samples were used to evaluate resistance to tracking and erosion under severe ambient conditions similar to those described in the ASTM D 2303 standard. Ammonium chloride (0.1%) with Antrox (0.02%), with a conductivity of 2.53 mS/cm, was used as a contaminating solution. In preparation for this test, five samples were sandpapered and cleaned with isopropyl alcohol. The operator defined the initial test voltage, which was increased in increments of 250V per hour until the end of the test, which was determined by the failure of several samples.

Mechanical tests

The samples for the mechanical tests were prepared on a full scale with dimensions of 90 x 112.5 x 2.400 mm and with standards holes, as illustrated by the diagram in Figure 3. These tests involved impregnated and non-impregnated wood. To identify the different samples during these tests, they were given the same codes as those of the electrical tests.

The bending strength properties were measured based on the ABNT standard [9], using a VICKERS®- model XG 06 F 20 hydraulic machine, a Mitutoyo® comparative clock - model BBY 051, No. 3058 F and a Templec® humidity and temperature meter. The tests were conducted at a temperature of 21°C and a relative air humidity of 61%.

A group of five samples of each wood species were tested. Figure 4 shows a detail of these tests. The forces were applied at two points and in situation A and B. In situation A, the forces were localized 10 cm from edge and, in situation B, 15cm from the edge. In both situations, the fixed point was located in the middle of the sample. A diagram of this test is shown in Figure 5.

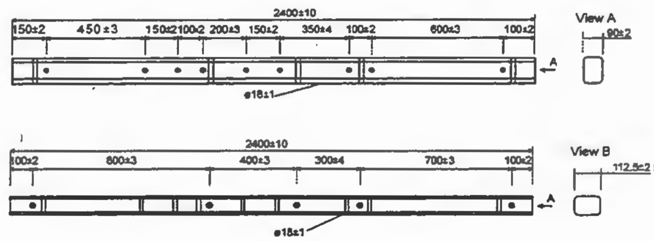

Figure 3 – Timber 2.4 meter crossarm with standard holes

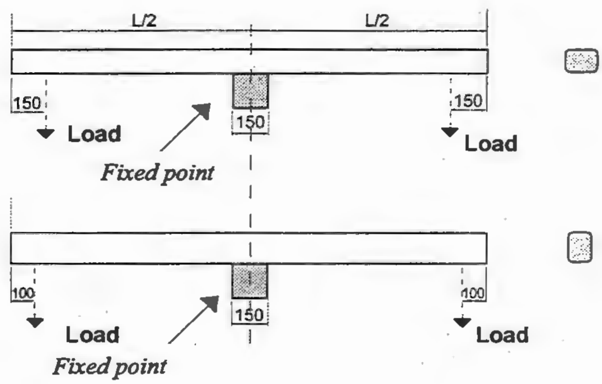

Figure 4 – Detail of the bending test

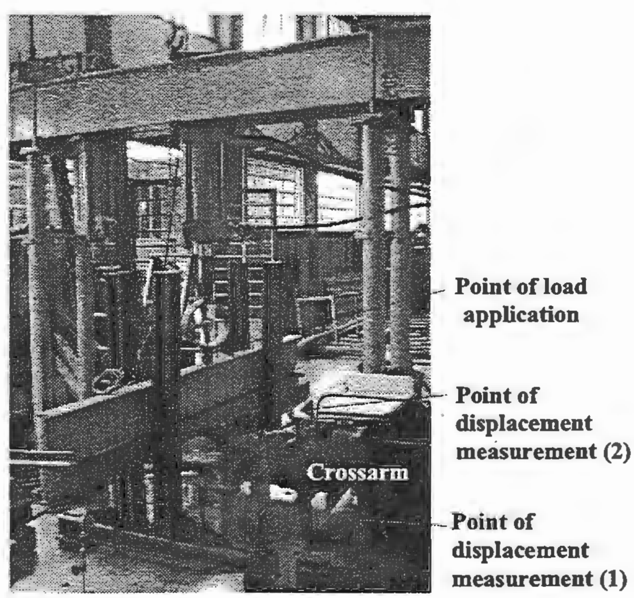

Figure 5 – View of the bending test

RESULTS

As shown in Figure 2, the polyurethane resin adhered very well to the wood, producing a bright surface with only a very slight change in the wood color. These two characteristics are important for increasing the mechanical strength and harmonizing the structure with the natural surroundings.

The bending test data for 400 kgf (3.9 kN) and 540 kgf (5.3 kN) listed, respectively, in Tables II and III indicate that oil-impregnated *Eucalyptus citriodora* displays excellent mechanical bending strength and a displacement value well below the maximum displacement allowed by the NBR-8458 standard. However, although its displacement value was lower than the maximum displacement recommended by the NBR 8458 standard, *Pinus elliottii* broke during the test at points where the wood contained a knot. Even so, the mechanical bending strength of both these wood species increased further with the application of polyurethane resin coating.

Table II
Bending load test for 400 kgf (3.9 kN)

2.4 meter Crossarm	Displacement measured (mm)		Maximum displacement allowed by NBR 8458 (mm)
	A	B	
Eucalyptus citriodora Oil-impregnated	5.73	7.95	115
Eucalyptus citriodora Oil-impregnated and polyurethane resin coated	4.79	6.21	115
Pinus elliottii in its natural state	17.62	24.30	115
Pinus elliottii in its natural state and polyurethane resin coated	9.12	13.25	115

Table III
Bending load test for 560 kgf (5.3 kN)

2.4 meters Crossarm	Displacement measured (mm)		Maximum Displacement allowed by NBR 8458 (mm)
	A	B	
Eucalyptus citriodora Oil-impregnated	8.12	11.08	163
Eucalyptus citriodora Oil-impregnated and polyurethane resin coated	6.56	8.60	163
*Pinus elliottii** in its natural state	25.14	33.63	163
*Pinus elliottii** in its natural state and polyurethane resin coated	12.55	18.12	163

* Rupture of the sample occurred during the test

Table IV, which lists the bending strength values, indicates that *Eucalyptus citriodora* showed an excellent performance, with a bending strength approximately 150% higher than the minimum bending strength admitted by the ABNT standard. Again, although the bending strength of *Pinus elliottii* was greater than the minimum bending strength recommended by the ABNT standard, its value is low; hence, this species cannot be recommended for this type of application.

Table IV
Crossarm bending strength

Crossarm made of	Bending strength (N)	Minimum Bending Strength allowed by the ABNT (N)
Eucalyptus citriodora Oil-impregnated	20.162	7.845
Eucalyptus citriodora Oil-impregnated and polyurethane resin coated	28.123	7.845
Pinus elliottii In its natural state	13.896*	7.845
Pinus elliottii in its natural state and polyurethane resin coated	10.502*	7.845

* Rupture of the sample occurred during the test

An analysis of the results of the electrical tests shown in Table V and of the results reported by reference [10] reveals that, in this impregnation process, the resin's electrical characteristics predominate over the wood's electrical characteristics, indicating the strong influence of the superficial resin layer.

Table V
Electrical characteristics of wood coated with polyurethane resin

Wood coated with polyurethane resin	Surface Resistivity ($\Omega.10^{15}$)	Dielectric dissipation factor $\tan\delta$) for 1.5kV	Dielectric dissipation factor ($\tan\delta$) for 2.0 kV
Eucalyptus citriodora Oil-impregnated	1.2	0.032	0.03
Pinus elliottii in its natural state	1.2	0.032	0.03

Table VI shows the results of the test to evaluate tracking and erosion resistance under severe ambient conditions, according to the ASTM D2303 standard.

Table VI
Tracking and erosion resistance under severe ambient conditions

Wood coated with polyurethane resin	Failure Voltage (kV)	Failure mode
Eucalyptus citriodora Oil-impregnated	2.0	Tracking within 1-3h
Pinus elliottii in its natural state	2.25	Tracking within 2-3h

CONCLUSIONS

An analysis of Table I indicates the excellent mechanical properties of reforested *Eucalyptus citriodora* compared with native tropical wood species and with reforested *Pinus elliottii*. These excellent properties were confirmed by crossarm mechanical tests, which revealed a bending strength for this application approximately three times superior to the minimum established by the ABNT standard. The results of the tests on this wood species coated with resin were even better. *Eucalyptus citriodora* impregnated with preservative oil showed a 10- to 30-year longer lifetime under natural weathering conditions. Since polyurethane resin has good hydrophobic properties, i.e., it is waterproof, wood coated with this resin will remain dry and, if not in contact with fungi or parasites, its mechanical strength and lifetime can be prolonged for many more years. Aging tests are being initiated to determine the average lifetime of *Eucalyptus citriodora* crossarms coated with polyurethane resin.

Though *Pinus Elliottii* coated with resin also passed the mechanical tests, its many weak points concentrated at its knots requires it be selected with special care. These weaknesses may limit its application for crossarm purposes.

Since these resins keep the wood dry, the electrical resistivity of wood, which normally varies greatly with moisture content especially below the fiber saturation point, stay stable in values about 10^{14} to 10^{16} $\Omega{\cdot}m$, improving the electrical characteristics of these crossarms. The resistances to tracking and the erosion under severe ambient conditions tests also have shown a positive impact on the electrical characteristics of these crossarm, increasing their Basic Impulse Insulation Level-BIL.

Hence, crossarms made of timber coated with polyurethane resin may be an alternative for power electric distribution system.

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Author's address: Ruy Alberto Corrêa Altafim, Department of Electrical Engineering - São Carlos School of Engineering - University of São Paulo, C.Postal 359 - CEP 13566-590 - São Carlos, SP, Brazil, E-mail: altafim@sel.eesc.sc.usp.br.