ONLINE ISSN 2069-7430
ISSN-L 1841-4737

PRO LIGNO
www.proligno.ro

Vol. 13 N° 4 2017
pp. 194-198

PHYSICAL AND MECHANICAL PROPERTIES OF TEAKWOOD LVL BONDED WITH EXPANDED POLYSTYRENE

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Abstract:

This study presents the physical and mechanical properties of teak LVLs bonded with expanded polystyrene (EPS). The hot-pressing was done at 145 °C, 1 MPa, for 8 min. Three EPS amounts were tested: 96 g/m², 192 g/m², and 288 g/m². We performed the following tests: thickness swelling (TS), water absorption (WA), static bending strength, non-destructive test with stress wave, and glue-line shearing. The panels produced with a amount of 288g/cm^2 presented better results for TS and WA after 2h and 24h. There was no significant difference for static and dynamic elasticity moduli *among treatments. The best treatment was 288 g/m² for the modulus of rupture. The stress wave analysis cannot be applied to the composite as a method for predicting mechanical properties. The treatments with 192 g/m² and 288 g/m² met the minimum requirements for shear strength according to standards EN 314-1 (2004) and ABNT ISO 12466-2 (2012) for dry indoor environments.*

Key words: *nondestructive evaluation; expanded polystyrene; Tectona grandis; wood plastic composite.*

INTRODUCTION

Studies of wood-plastic composites have been carried out since the late 1960s (Rowell et al. 2002). Plastic as a matrix improves the material characteristics, such as resistance to moisture, and insects and fungi attack. Wood particles, such as polymer matrix reinforcement, improve mechanical properties and provide greater composite thermal stability. However, volatiles release, lignocellulosic particle degradation, or even carbonization may occur at temperatures above 200°C (required for the glass transition of some plastics). Therefore, the plastic-wood composites formulations are restricted to thermoplastics with low processing temperatures. Polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), and polystyrene (PS) - with low or moderate crystalline melting temperatures - are among the thermoplastic polymers used for the production of wood-plastic composites (WPCs) (Chindaprasirt et al. 2015).

Polystyrene (PS) is an aromatic polymer made from the styrene monomer, with a glass transition temperature (Tg) of 100°C. Above this temperature, the material gradually liquefies. (Lisperguer et al. 2011). It is characterized by low density, high transparency, and good mechanical properties. It is the third most widely used thermoplastic in industries worldwide, with low production cost and easy processing. In its expanded form (EPS) it is used in packaging and as an insulating material, due to its versatility and dimensional stability. However, after use, it is generally discarded into landfills or incinerated (Poletto et al. 2011).

EPS is a chemically inert, non-biodegradable, but 100% recyclable material. If not recycled, however, it is an environmental problem due to the space occupied by this material in landfills. (Chagas et al. 2011). Poletto et al. (2011) and Lisperguer et al. (2011) have already investigated the use of polystyrene composites as a matrix reinforced with powder and wood particles. In our previous work (Del Menezzi et al. 2016) it was demonstrated that it is possible to use EPS for bonding wood veneers to manufacture laminated veneer lumber (LVL).

OBJECTIVE

The main goal of this study was to deep our previous work (Del Menezzi et al. 2016) by determining physical and mechanical properties and performs the technical feasibility of the production of *Tectona grandis* LVLs bonded with EPS, with three different amounts of EPS.

METHOD, MATERIALS, AND EQUIPMENT

The study was carried out in Brasília-DF, Brazil, in the Laboratory of Wood Technology, Department of Forest Engineering, University of Brasília, and in the Laboratory of Forest Products of the Brazilian Forest Service. The study used 1.2-mm rotary peeled veneers of teakwood (*Tectona grandis*). They were produced from logs of a commercial forest stand with 13 years of age implanted in the Municipality of Juara/ MT. Lamination was performed with a lathe at Sharewood do Brasil Ltda. Expanded polystyrene (EPS) sheets (Styrofoam® plates) were used as a thermoplastic adhesive. They were available locally, with dimensions of 50x100x0.8cm, and density of 96g/m^3. Three treatments with different EPS amount (96g/m², 192g/m², and 288 g/m²) were tested in five replicates, totaling 15 panels. Panels were assembled by inserting *T. grandis* veneers and polystyrene layers, totaling five wood layers and four polystyrene layers. The panel was pressed using Indumec hot-press, at a temperature of 145°C, pressure of 1MPa, for 8 minutes. Panels with the dimensions of 20x20x0.77cm were obtained. The assembled panels were conditioned in an acclimatization room with a relative humidity of 60 ± 5%, and temperature of 20 ± 1°C until constant mass. The following physical and mechanical tests were performed (Table 1):

Table 1

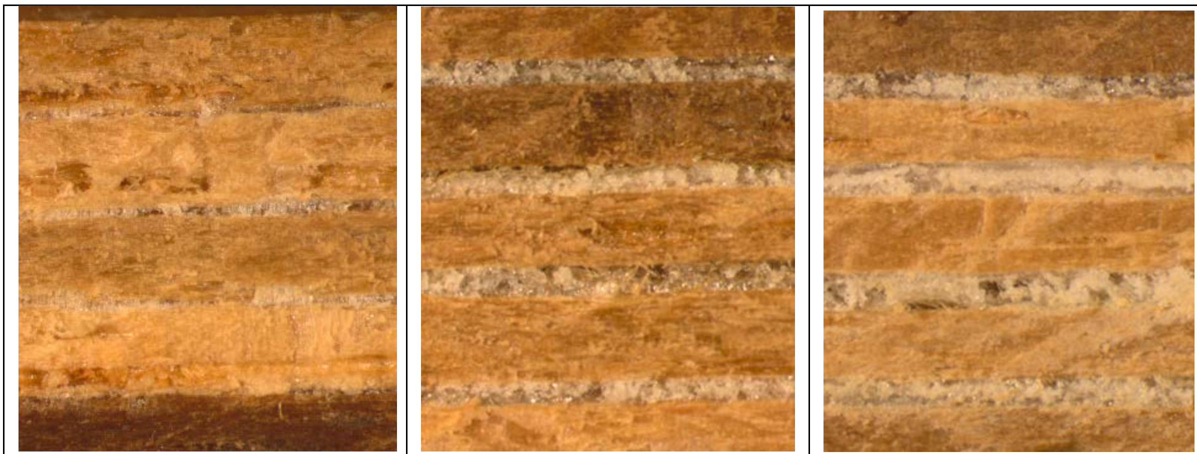
Tests performed for physical and mechanical characterization and applied standards

Test	Standard
Water absorption (WA) and thickness swelling (TS), 2h and 24h	ASTM D-1037 (2006);
Static flexural strength - Modulus of elasticity (E_M) and Modulus of rupture (f_m), ASTM D-1037 (2006);	ASTM D-1037 (2006);
Stress wave dynamic elastic modulus (E_d)	Del Menezzi et al. (2016);
Shear strength parallel to the glue line - (fv), dry test	EN 314-1 (2004) and ABNT ISO 12466-2 (2012)

The experiment was conducted in a completely randomized design (CRD). Statistical analysis was performed by the ANOVA and Tukey tests, at 5% significance. A simple linear regression model was also generated from joining all the treatments in a single group, correlating E_d with E_M and f_m in order to identify the predictability of the mechanical properties using nondestructive test.

RESULTS AND DISCUSSION

The panels with the three EPS amounts had densities which did not differ significantly from each other. However, the differences between the thicknesses of glue lines in the three treatments are perceptible, as well as the glue line porosity (Fig. 1).



96 g/m²	192 g/m²,	288 g/m²

Fig. 1.
Glue lines of panels produced with different amounts and PS.

The panels produced with of 288g/cm^2 showed better results for WA and TS properties, for both 2 hours and 24 hours (Table 2). There was a tendency of reduction for WA and TS with an increase in OS, possibly due to the hydrophobic characteristics of the thermoplastic material used in the glue.

Table 2

Mean values and standard deviation for apparent density at 12% (ρ), water absorption (WA), and thickness swelling (TS), as a function of EPS amount

EPS amount	ρ (g/cm³)	WA-2h (%)	WA-24h (%)	IE-2h (%)	IE-24h (%)
0.96 (g/m^2)	0.60a	9.61 (±1.9) a	36.08 (±2.7) a	3.55 (±2.3) a	4.92 (±1.8) a
1.92 (g/m^2)	0.62a	7.97 (±1.0) a	30.26 (±3.9) b	1.95 (±2.7) b	3.84 (±1.4) a
2.88 (g/m^2)	0.59a	5.02 (±0.4) b	25.20 (±2.8) c	0.93 (±1.2) c	1.87 (±0.5) b

Means followed by the same letter in the same column do not differ from each other by the Tukey test at the 5% significance level.

The EPS amounts did not significantly influence the dynamic modulus of elasticity and the static modulus of elasticity (Table 3). The modulus of rupture of the panels produced with the highest EPS amount was superior. Iwakiri et al. (2014) reported higher values for modulus of elasticity (12,450 to 14,274MPa), and similar ones for modulus of rupture (43 to 85MPa) on teak LVL panels bonded with resorcinol-phenol-formaldehyde, polyurethane, and isocyanate.

Table 3

Mean values and standard deviation of mechanical properties of teak LVL bonded with polystyrene as as a function of EPS amount

EPS amount	E_d (MPa)	E_M (MPa)	f_m (MPa)
96 g/m²	6675.9 (±1466.9) a	8469.8 (±1943.3) a	49.3 (±6.9) b
192 g/m²	7506.5 (±835.6) a	8872.4 (±2172.1) a	53.6 (±12.2) b
288 g/m²	6701.8 (±2206.2) a	9132.6 (±1115.8) a	74.1 (±12.2) a

Means followed by the same letter in the same column do not differ from each other by the Tukey test at the 5% significance level.

The values of modulus of elasticity (E_M) were higher than E_d for all treatments, which is considered atypical for woods. Teles et al. (2011), evaluated the interrelationships between three non-destructive methods and the rigidity in *Sextonia rubra* boards, and Ed was 3.5% higher than Em. Other studies with several species corroborate with the study previously mentioned (Karlinasari et al. 2008; Bucur and Declercq 2006). Nzocou et al. (2006), when analyzing wood-plastic composites with polyvinyl chloride (PVC), also obtained higher values for E_d (17.6%) in comparison with E_M. Glue line porosity (Fig. 1) may have retarded the wave propagation velocity in the stress wave test, but with less influence on material strength.

The simple linear regression model did not indicate a correlation between the two mechanical properties found in destructive tests with low coefficients of determination (R²) (Figs. 2 and 3). Nzokou et al. (2006) suggest that the nondestructive stress wave technique may not be appropriate for the prediction of modulus of elasticity in bending of plastic-wood composites.

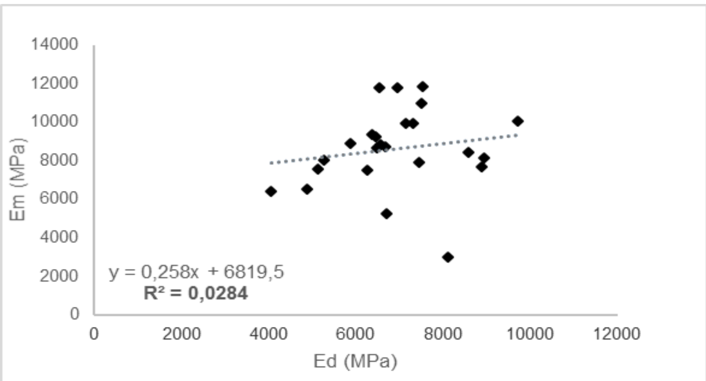


Fig. 2.
Simple linear regression model for Em and Ed.

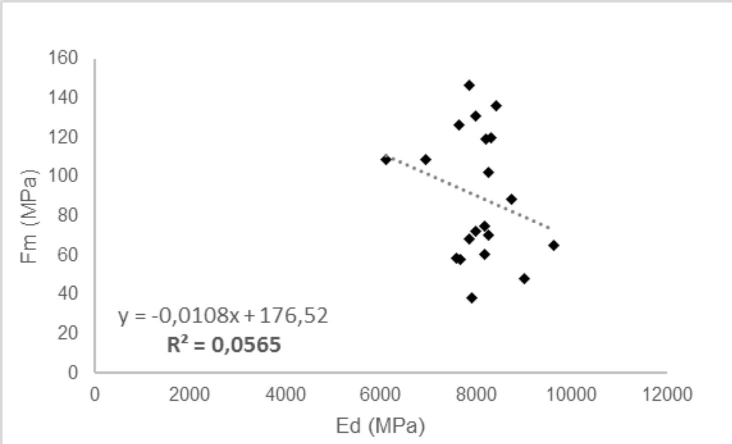


Fig. 3.
Simple linear regression model for Fm and Ed.

The shear strength (fv) (Table 4) of the panels with 288g/m² of polystyrene was the highest; however, the amount of 192g/m² also met the bonding requirements of standards EN 314-1 (2004), and ABNT ISO 12466-2 (2012), in indoor and dry environments.

Table 4

Mean values of the shear strength of LVLs as a function of EPS amount.

EPS amount	Shear strength (MPa)	EN 314-1	ABNT ISO 12466-2
96 g/m²	0.92 (±0.46) b	not met	not met
192 g/m²	1.21 (±0.21) ab	met	met
288 g/m²	1.39 (±0.29) a	met	met

Means followed by the same letter in the same column do not differ by the Tukey test at 5% significance level. *Parameters referring to class 1 of panels, for indoor and dry environments.

Lima et al. (2013) studied resorcinol-formaldehyde LVLs (160g/m²) of different compositions of *Pinus oocarpa*, and three Amazonian species with densities similar to those of the present study, and found higher fv values ranging from 4.70MPa to 5.15MPa. Lustosa el al. (2015) produced LVLs bonded with high-density polyethylene and found higher values (2.32MPa). Iwakiri et al. (2010) also obtained higher values (2.05MPa) in LVLs of *Eucalyptus saligna/Schizolobium amazonicum* bonded with phenol formaldehyde. Miranda et al. (2011) verified the presence of 9.2% to 10% of extracts in *T. grandis*, which may have negatively influenced bonding.

CONCLUSIONS

The present study confirms our previous work about the technical feasibility in the production of teakwood LVLs bonded with EPS for indoor and dry environments. The LVLs made with a amount of 288g/m² performed better in the physical and mechanical tests. However, the treatment with 192g/cm² also obtained good results, reaching the minimum plywood quality parameters of standard EN 314-1 (2004). Considering that the latter uses less polystyrene, this amount is recommended for economic reasons.

ACKNOWLEDGEMENT

The authors are greatful to Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for providing research funds to develop these studies and to Fundação de Amparo à Pesquisa do Distrito Federal (FAP-DF) for travel funds which have made it possible to attend this conference.

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