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ESTIMATING HARDNESS OF EUCALYPTUS WOOD WITH A PORTABLE HARDNESS TESTER

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ABSTRACT: More than 80% of the 29600 km of the Brazilian railroad mesh employs wooden sleepers. The problem of hard availability of native wood for this purpose leads to the alternative use of reforestation species to produce sleepers. Considering the great difficulty to, in field condition, evaluate characteristics that are of major importance to define its suitability to sleeper production the Research Group on Forest Products from FCA/UNESP – Brazil had developed equipment for field evaluation of hardness in wood – Portable Hardness Tester. This paper reports the functional validation tests, performed with different species of *Eucalyptus*. Results revealed the equipment great functionality, easy-to-use characteristics and applicability to *Eucalyptus* wood. Moderate to strong relationships between laboratory and validated values of hardness were found. The best validation model was obtained using the data provided by the experimental dispositive 3 (R^2=0.74 and SSE= 7.71 kJ/m²) while the experimental dispositive 1 gave the worse validation (R^2=0.55 and SSE= 13.46 kJ/m²).

KEYWORDS: hardness, portable equipment, *Eucalyptus*

1 INTRODUCTION

Brazilian railroads companies largely use wooden sleepers (ties) in their meshes. During the early implantation period of these railways (first half of last century) there was a large availability of native wood species for this purpose (*Astronium urundeuva, Tecoma* sp*., Hymenaea stilbocarpa, Myrocarpus* sp.).

Nowadays companies are facing very difficult situation, with increasing deficits of sleepers, environmental regulations to the use of sustainable resources and increasing prices of the native wood species suitable for this purpose.

The alternative, at short and medium term, has been the use of reforestation species to produce sleepers. In this new scenario, the great difficulty, in field condition, is the classification of species (most of them very similar in a visual analysis) and the evaluation of additional characteristics (age, e.g.) that are of major importance to define its suitability to sleeper production.

Among the major strength properties of wood, hardness reveals its potentialities (good correlation to other mechanical properties and quickness of results) and can be used as a non-destructive tool in the characterization of species from reforestation [1,2].

General methods to evaluate hardness in materials are gathered in two major groups. In the first one, hardness is evaluated by the required force to promote a defined surface indentation in the material (Janka hardness, e.g.). In the second group hardness is evaluated by the surface indentation (deformation) promoted by a pre-defined force (Brinell hardness, e.g.). The dimensions and shapes of the pieces and the magnitude of the force are determined by the method adopted. Despite the major appropriation of Janka hardness to wood measurements several researchers [3,4] have suggested Brinell method for the evaluation of hardness in wood in field condition, considering the lower magnitude of the forces involved in the indentation and the additional difficulty to control, the depth of the metal sphere indentation required on Janka hardness method.

Ballarin et al. [5] had reported the development and calibration of a Portable Hardness Tester, used in the evaluation of sixteen groups of native and reforested wood (193 specimens). The equipment demonstrated acceptable level of accuracy to classify these groups. Evaluating specimens in the upper bands of Janka hardness ($f_H \geq 50$ MPa and 40 MPa$\leq f_H < 50$ MPa) the inclusion errors obtained were from 4.5% to 16.6%.

This paper reports the functional validation tests performed with the Portable Hardness Tester with an

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independent set of different species of *Eucalyptus* used on sleeper production.

2 MATERIAL AND METHODS

General characteristics of the portable hardness tester are described in Ballarin et al. [5]. Hardness was determined classically – direction perpendicular to the grain of wood – using an universal testing machine (f_H, MPa) and estimated alternatively by the Portable Hardness Tester providing hardness information labelled as H_1, H_2, H_3 and H_4 according to the experimental procedures:

H_1 – free fall of 1 kg mass from 100 mm height
Energy = 0.98 J

H_2 – free fall of 1 kg mass from 200 mm height
Energy = 1.96 J

H_3 – free fall of 2 kg mass from 100 mm height
Energy = 1.96 J

H_4 – free fall of 2 kg mass from 100 mm height
Energy = 3.92 J

Hardness strength (H) was evaluated considering the energy at the impact of the metal sphere against the wood specimen, according to the expression:

$$H = \frac{2E}{\pi D\left(D - \sqrt{D^2 - d^2}\right)} \quad , d > 0 \qquad (1)$$

where H = hardness strength, E = energy resulted from the free fall of the mass, D = diameter of the metal sphere, d = indented diameter in the wood.

The calibrated models (hardness H_1 to H_4 as a function of hardness Janka – f_H) obtained [3] were validated using an independent set.

Seven specimens of eucalyptus were used to perform the experimental tests. Two samples (one with pure heartwood and other with the presence of sapwood) with 12 specimens were obtained for each specie evaluated, totalizing 168 specimens. Table 1 presents the major characteristics of the wood species analyzed.

Table 1: *Main characteristics of the groups of* Eucalyptus *wood*

Group	Specie	Age of the Plantation (years)	Average density(*) (kg/m³)
1	*E.maculata*	35	810
2	*E.microcorys*	35	770
3	*E. tereticornis*	40	950
4	*E. citriodora*	44	980
5	*E. saligna*	50	690
6	*E. dunnii*	20-23	750
7	*E. viminalis*	20	720

(*) – Apparent density based on mass and volume at 12%MC – values reported by suppliers

Figures 1 and 2 illustrate components and general aspects of the Portable Hardness Tester and details of the indentation promoted in wood, respectively.

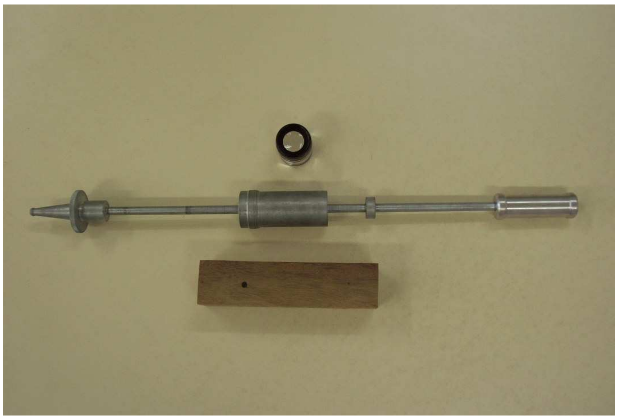

Figure 1: *Details of indentation promoted by the Portable Hardness Tester in wood.*

Figure 2: *Details of indentation promoted by the Portable Hardness Tester in wood.*

3 RESULTS AND DISCUSSION

Tables 2 and 3 present descriptive statistics of the calibration and validation sets.

Table 2: *Descriptive statistics of the calibration set*

Descrip. Statist.	f_H (MPa)	H_1 (kJ/m²)	H_2	H_3	H_4	f_{c0} (MPa)
Mean	56.73	37.35	54.79	49.98	71.26	43.02
sd	23.29	9.55	13.60	11.99	17.07	13.62
Min	14.89	18.43	25.04	22.53	30.16	19.00
Max	102.60	59.72	83.80	74.21	107.74	81.85
CV (%)	41.1	25.6	24.8	24.0	24.0	31.7
N	193	193	193	193	193	190

Table 3: *Descriptive statistics of the validation set*

Descrip. Statist.	f_H (MPa)	H_1 (kJ/m²)	H_2	H_3	H_4
Mean	61.74	36.42	50.84	45.77	69.59
sd	21.36	8.23	9.51	8.52	14.03
Min	20.10	18.74	28.69	24.61	35.48
Max	121.80	61.16	75.70	68.62	107.74
CV	34.6	22.6	18.7	18.6	20.2
N	168	168	168	168	168

Figure 3 presents the calibration models obtained for Hardness Janka estimation based on H_1, H_2, H_3 and H_4.

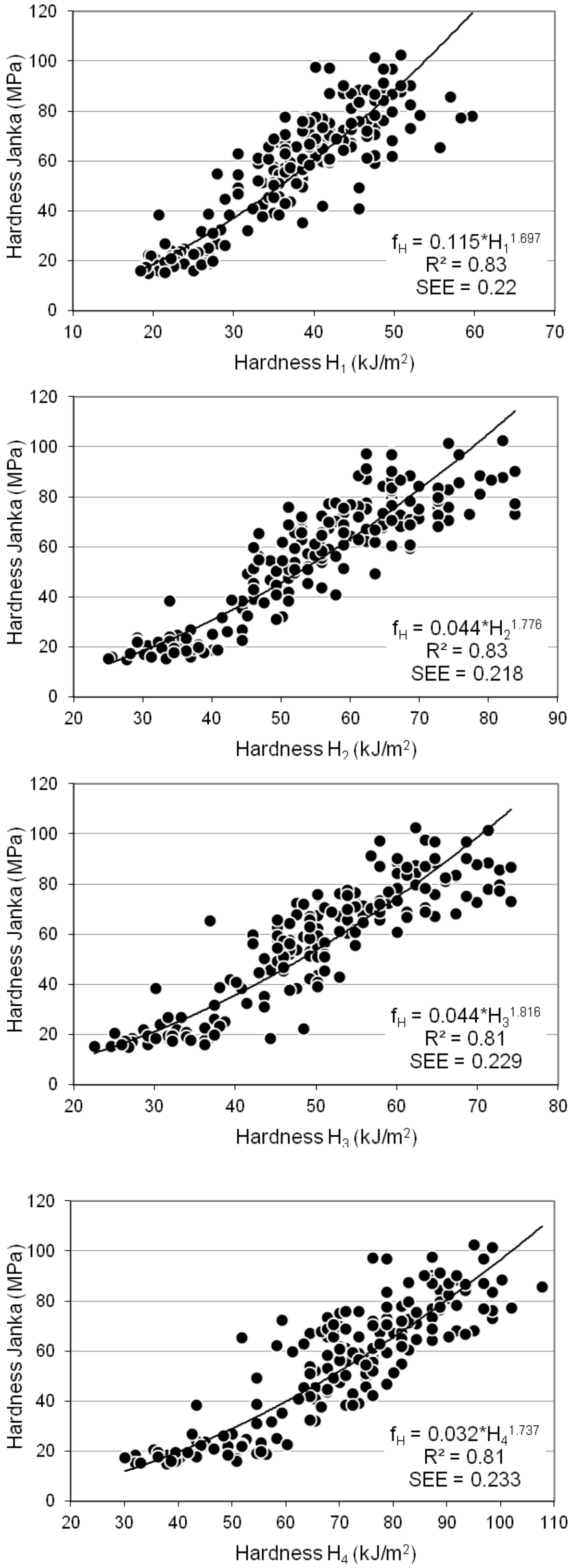

Figure 3: *Hardness Janka versus Hardness H_i evaluated by the Portable Hardness Tester in four distinct energy levels (H_1 to H_4)*

The plots of Lab-measured Hardness Janka (f_H) and validated values H_i (H_1... H_4) are presented in Figure 4. Correspondent descriptive statistics are shown in Table 4.

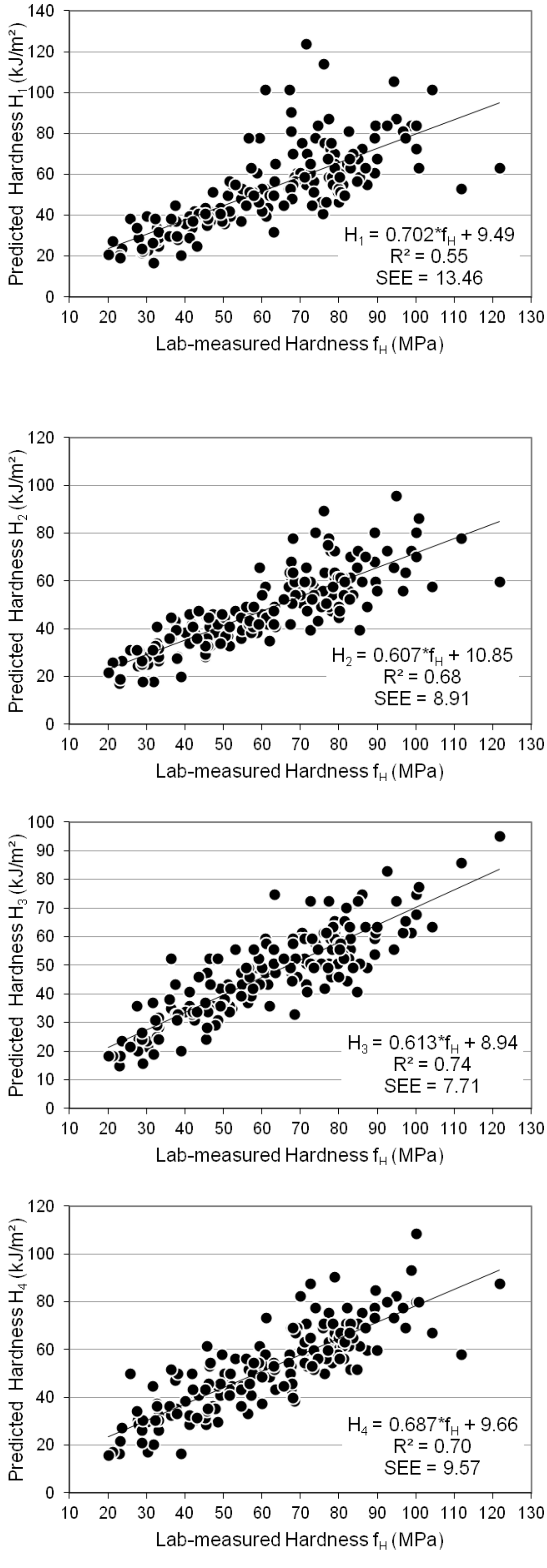

Figure 4: *Laboratory measured versus H_i predicted values plot for hardness of Eucalyptus wood by linear model. SSE is the standard error of estimation.*

Relating to results from Tables 2 and 3, it is observed in both sets (calibration and validation) lower coefficient of variation of the results obtained from the Portable Hardness Tester (18.6 ≤ CV ≤ 25.6). Results from conventional mechanical tests (mainly Hardness Janka) presented almost the double variation (34.6 ≤ CV ≤ 41.1). In a first moment, this occurrence could be associated to low sensitivity of the equipment to technological differences of the specimens. Despite this, strong correlations were obtained in the association showed in Figure 1.

Table 4: *Descriptive statistics of Lab-measured Hardness Janka and its estimation by the Portable Hardness Tester*

	Lab-meas	Estim. H_1	Estim. H_2	Estim. H_3	Estim. H_4
Mean	61.74	52.85	48.31	46.77	52.10
sd	21.36	20.13	15.71	15.18	17.51
Min	20.10	16.62	17.08	14.79	15.76
Max	121.80	123.70	95.66	95.15	108.49
CV	34.6	38.1	32.5	32.4	33.6
N	168	168	168	168	168

Validation models for the equipment are presented in Table 5.

Table 5: *Validation models*

Validation Model	Coef. of determ. (R^2)	SEE ($kJ/.m^{-2}$)
H_1=0.702f_H+9.49	0.55	13.46
H_2=0,607f_H+10.85	0.68	8.91
H_3=0,613f_H+8.94	0.74	7.71
H_4=0.687f_H+9.66	0.70	9.57

Moderate to strong relationships between laboratory and validated values of hardness were found.

The best validation model was obtained using the data provided by the experimental situation 3 (R^2=0.74 and SSE= 7.71 kJ/m², Figure 4) while the experimental situation 1 gave the worse validation (R^2=0.55 and SSE= 13.46 kJ/m², Figure 4).

Based on these results a new generation of the equipment has been evaluated using accelerometer Measurement Specialties, model EGCS-DO (Figure 5), to automatically evaluate indentation without direct measurement of the indented diameter in wood. Preliminary results have shown the possibility of association of acceleration, velocity and displacements to viscoelastic parameters of wood.

4 CONCLUSIONS

From the experimental program the following main conclusions can be established:

- Portable Hardness Tester presented reliable response in the evaluation of Eucalyptus wood used in sleepers production;
- Despite determination coefficients (R^2) of the calibration regression between hardness (H_1 to H_4) and Janka hardness exceeded 0.80 [5], only moderate to strong relationships between laboratory and validated values were obtained, with best validation model reaching R^2=0.74.

Figure 5: *Details of new generation Portable Hardness Tester in wood with accelerometers*

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