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Quality Assessment in Industrial Production of Plywood by Stiffness and Strength Properties in Bending

Tiago Hendrigo de Almeida[1], Diego Henrique de Almeida[2], Felipe Hideyoshi Icimoto[3], Cristiane Inácio de Campos[1], Luciano Donizeti Varanda[3], André Luis Christoforo[4,*], Francisco Antonio Rocco Lahr[2]

[1]Department of Wood Engineering, Paulista State University, Experimental Campus of Itapeva, Itapeva, 18409-010, Brazil
[2]Department of Structural Engineering, Engineering School of São Carlos (EESC/USP), São Carlos, 13566-590, Brazil
[3]Department of Science and Engineering Material, Engineering School of São Carlos (EESC/USP), São Carlos, 13566-590, Brazil
[4]Department of Mechanical Engineering, Federal University of São João del-Rei, São João del-Rei, 36307-352, Brazil

Abstract This research aimed to investigate, by means of the strength (MOR) and stiffness (MOE) properties in bending, the homogeneity in the manufacture of plywood (*Pinus* sp wood and phenolic resin) produced by an industry located in the state of Paraná (PR - Brazil). The factors and levels investigated in this study were the choice of panels (A, B, C and D), the extraction position of the specimens (Center; Side) and fiber orientation (Parallel, Perpendicular), providing a full factorial design of $4^1 2^2$ type, with 16 different treatments. On the panel, were extracted 20 specimens (500×75×18mm) for bending tests. ANOVA results showed that the choice of panel and fiber orientation was significant in the properties of strength and stiffness in bending, this is not occurring with the extraction position of the specimens. The MOR and MOE of the specimens obtained in the parallel direction were 87% and 141% higher than the MOR and MOE of the specimens evaluated in the perpendicular direction, respectively, and with respect to non-equivalence found between the mechanical properties by the choice of the panel, for results with greater reliability it is necessary the development of new research with a significantly higher number of plywood.

Keywords Plywood, Pinus wood, Phenolic resin, Design of experiments, Analysis of variance

1. Introduction

The plywood is a panel based on wood veneers bonded with adhesive, pressure and high temperature for cross-lamination technique, that is, the direction of the grain of a veneer is perpendicular to grain veneer adjacent.

The arrangement of the wood veneer on panel and the use of adhesive provide to plywood greater dimensional stability and mechanical properties more uniform compared to wood, decreasing the anisotropy of solid wood.

Adhesives for plywood most used industrially are urea-formaldehyde, melamine-formaldehyde and phenol-formaldehyde. Determinant for life of plywood is its correct use in accordance with its recommendation for use. Generically, for internal, intermediate and external uses are recommended, respectively, adhesives urea-formaldehyde, melamine-formaldehyde and phenol-formaldehyde[1].

Currently there is a scarcity of tropical wood for various purposes, including for use as raw material in industries that produce veneer and plywood. A good alternative to meet the demand of this sector providing good quality woods are the reforestation of *Pinus* and *Eucalyptus*[2, 3].

The researches about the properties of strength and stiffness of plywood using *Pinus* wood are important for purposes that may be earmarked, including civil construction and industry[2, 4, and 5].

Among the mechanical properties that should be known to characterize a lot of plywood, we have the modulus of elasticity (MOE) and modulus of rupture (MOR). In Brazil, these characteristics are determined from mechanical tests normalized by ABNT NBR 9533[6] "Determination of strength to bending plywood".

Research about values of MOE and MOR of plywood produced with *Pinus taeda* and *Pinus oocarpa* with three different formulations of adhesive phenol-formaldehyde revealed that the anatomical characteristics of the wood (adult and juvenile wood, width of growth rings and early and late wood) have influenced the mechanical properties of the plywood[7].

Others researches has shown that plywoods of *Pinus sp.* with three different formulations of PVA adhesive and two combinations of temperature and time of pressing, finding lower values of MOE and MOR compared to panels made

* Corresponding author:
alchristoforo@yahoo.com.br (André Luis Christoforo)
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with urea-formaldehyde and phenol formaldehyde adhesives, which are the most used by the industrial sector[8].

Research with plywood made with wood from a hybrid *Pinus elliottii var. caribea* x *Pinus elliottii var. hondurensis* analyzing two points removed of the tree trunk, two adhesive grammages (380 and 420 g /cm²) and two times of pressings (8 and 12 minutes). Among the authors' conclusions, the wood of this hybrid presented good results for making plywood for purposes such as civil construction, furniture and packaging[9].

The aim of this research consists to analyze the variation of the values of MOE and MOR at different points of same plywood panels produced industrially for evaluation of homogeneity of the industrial manufacturing process of plywood.

2. Material and Methods

For this research we used four panels of plywood collected on the line production of an industry of Paraná (PR - Brazil). The panels were manufactured with wood veneers of *Pinus sp.* with dimensions of 1.25m×2.50m×18 mm, with 13 veneers in each panel bonded with phenolic resin.

Were fabricated and tested 80 specimens for bending tests according to the procedures of the normative document ABNT NBR 9533[6]. With the purpose of determining the influence of the withdrawal position of the specimens in the MOE and MOR, 40 specimens were removed from the center and the others 40 removed from the edge of the panel in parallel and perpendicular directions to the grain of the external veneer (Figure 1).

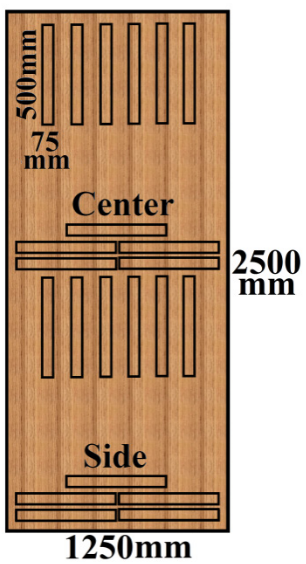


Figure 1. Scheme of specimens extraction of the plywood

After extraction of the specimens, they were tested in a universal testing machine DL 30000N according to the guidelines of the normative document ABNT NBR 9533[6]. The testing occurred in the Laboratory of Materials Properties of Experimental Campus Itapeva of Paulista State University (UNESP).

The factors and levels investigated in this study were the panels[Bo] (A; B; C; D), the extraction position of the specimens[EP] (Center (C); Side (S)) and fiber orientation [FO] (Parallel (Pa); Perpendicular (Pe)), providing a full factorial design of the $4^1 2^2$ type, with 16 distinct treatments (Tr), explained in Table 1.

Table 1. Treatments evaluated

Tr	Panel [Bo]	Extraction [EP]	Orientation [FO]
Tr 1	A	Center	Parallel
Tr 2	A	Center	Perpendicular
Tr 3	A	Side	Parallel
Tr 4	A	Side	Perpendicular
Tr 5	B	Center	Parallel
Tr 6	B	Center	Perpendicular
Tr 7	B	Side	Parallel
Tr 8	B	Side	Perpendicular
Tr 9	C	Center	Parallel
Tr 10	C	Center	Perpendicular
Tr 11	C	Side	Parallel
Tr 12	C	Side	Perpendicular
Tr 13	D	Center	Parallel
Tr 14	D	Center	Perpendicular
Tr 15	D	Side	Parallel
Tr 16	D	Side	Perpendicular

The factors and interactions of the factorial design were evaluated via analysis of variance (ANOVA) at the 5% level of significance (α), assuming the equivalence between the treatment means as null hypothesis (H_0) and the non-equivalence between means as alternative hypothesis (H_1). P-value less than the significance level implies rejecting the null hypothesis, accept it otherwise. To validate the ANOVA, Anderson-Darling (normality) and Bartlett and Levene (homogeneity of variances) test were used, both formulated at a significance level of 5%. For the Anderson-Darling test, the null hypothesis assumed was the normality of distributions, and non-normality as the alternative hypothesis. P-value greater than 5% implies accepting H_0, rejecting it otherwise. For Bartlett and Levine's tests, the null hypothesis assumed was the homogeneity of variances between treatments, and the non-equivalence as the alternative hypothesis. P-value greater than 5% implies accepting H_0, rejecting it otherwise. Factors considered significant by ANOVA, the sequence was used the Tukey test for multiple comparisons.

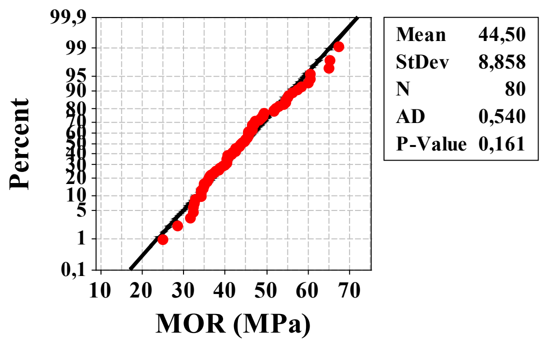
3. Results and Discussions

Table 2 presents the average values ($\bar{x}$) and coefficients of variation (CV) of the MOR and MOE of the panels evaluated.

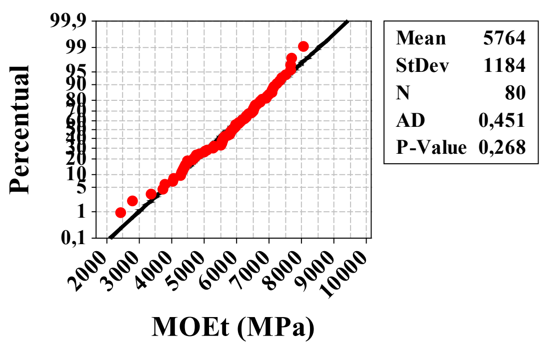
Table 2. Results of MOR and MOE of the panels

Tr	MOR (MPa)		MOE (MPa)	
	$\bar{x}$	*Cv(%)*	$\bar{x}$	*Cv(%)*
Tr 1	53.05	12	8706	10
Tr 2	31.47	20	3615	13
Tr 3	52.09	15	7938	7
Tr 4	30.14	16	4060	7
Tr 5	67.49	12	9318	4
Tr 6	21.3	18	996	19
Tr 7	55.57	4	8650	13
Tr 8	28.85	18	3272	10
Tr 9	55.97	6	8399	8
Tr 10	36.22	14	4438	11
Tr 11	46.33	20	7657	15
Tr 12	29.69	23	3840	18
Tr 13	61.95	12	8996	10
Tr 14	31.31	22	4050	16
Tr 15	62.93	11	8572	5
Tr 16	34.26	21	4082	14

Figures 2 and 3 show the results of normality and homogeneity of variance, respectively. For P-values found are both greater than 5%, given that the distributions are normal and the variances between treatments are equal, validating the model ANOVA.

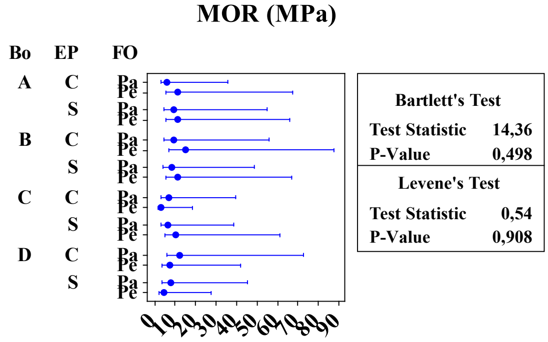


(a)

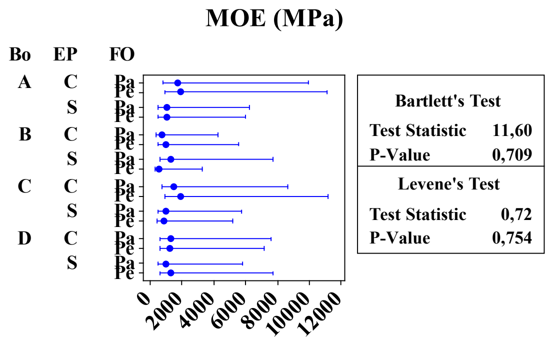


(b)

Figure 2. Results of normality tests: MOR (a) and MOE (b)



(a)



(b)

Figure 3. Results of the homogeneity of variance tests: MOR (a) and EOM (b)

Table 3 presents the ANOVA results for the MOR and MOE of plywood, with underlined P-values considered significant (P-value <.05).

Table 3. Results of ANOVA for the MOR and MOE

Source	DF	MOR P-value	MOE P-value
Bo	3	0,030	0,001
EP	1	0,127	0,709
Fo	1	0,000	0,000
Bo×EP	3	0,140	0,008
Bo×FO	3	0,000	0,000
EP×FO	1	0,052	0,000
Bo×EP×FO	3	0,097	0,067
Error	64		
Total	79		

From Table 3, it appears that the choice of plywood and fiber orientation to obtain the modulus of elasticity and strength in bending were considered significant by ANOVA, which did not occur with the extraction position, which provided equivalent values for both properties, revealing the uniformity achieved in the manufacture of the panel.

By fiber orientation was expected that the MOE and MOR in parallel direction were significantly higher than the MOE and MOR in the perpendicular direction. As to the choice of the panels, it was expected that the results of the properties of stiffness and strength were equivalent, which has not occurred, indicated inhomogeneity in the manufacture of the panels. These results may be different for a considerable number of samples, highlighting the need for further studies. Table 4 presents the results of Tukey's test for grouping (Gr) the levels of the factors considered significant by ANOVA. From Table 4, the same letters imply average with equivalent treatments.

Table 4. Results of Tukey test

		MOR		MOE	
Factors	**Levels**	$\bar{x}$ (MPa)	Gr	$\bar{x}$ (MPa)	Gr
Bo	A	41,69	b	6080	b
	B	43,30	b	5559	b
	C	42,05	b	6083	b
	D	47,61	a	6425	a
FO	Pa	56,92	a	8530	a
	Pe	30,41	b	3544	b

The MOR and MOE of the specimens obtained in the parallel direction were 87% and 141% higher than the MOR and MOE of the specimens evaluated in the perpendicular direction, respectively.

4. Conclusions

The results showed that the choice of the panels used in the development of this research was significant in the properties of strength and stiffness in bending, this is not occurring with the extraction position of the specimen panel, which provided equivalent results.

The values of MOE and MOR for the fiber orientation factor was significant, with those extracted from the fibers in the direction parallel the best results, as expected.

Even with a significant choice of panels in obtaining the properties of strength and stiffness in bending, so one cannot conclude on the homogeneity achieved in the manufacture of the panels by the company it is necessary the development of new research with a significantly higher number of panels, thus increasing the reliability of the results.

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