



STUDY OF THE PLYWOOD PANELS PROPERTIES USING GEOSTATISTIC

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ABSTRACT

Plywood panels have multiple applications in construction, in the furniture industry and packaging. There is a need to improve techniques for assessing quality of these products. This paper proposed the use of geostatistics to evaluate the behavior of the of the plywood panel.



The physical properties were analyzed (moisture content, density and water absorption) in the full extent of the plywood panel of *Eucalyptus sp.*, bonded with adhesive single-component polyurethane. For analysis, three panels of five layers, with dimensions of 350 x 350 x 15.5 mm each, were employed. The tests were based on the standards EN 323-2000, EN 322-2000 and ABNT NBR 9486- 2011. Statistical modeling was performed using the R software, using the methodology of geostatistics. The average results were compared with values reported in the literature. The average water absorption was 7% higher in comparison with other studies, which used urea formaldehyde. So, the product can be applied only to interior and their use is not advisable for floors; the average moisture content and density were within the average values found in the literature. The behavior of the properties analyzed using the geostatistical model was not homogeneous, with large variations. Geostatistics was considered an appropriate tool for the study of the variability of the plywood panel properties, and can be applied for better quality control of them.

Keywords: plywood; moisture content; density; water absorption; geostatistics

1. INTRODUCTION

In order to maintain its competitiveness, the company has invested in innovative tools focused on the process management, production process and product, as discussed by Petter et al. (2013). Petter et al. (2013) found that the highest concentration of innovative activities, in furniture, is focused on the product (54%). In this context, new products have been development and improved, as is the case of the plywood panels.

Plywoods are veneers overlapped and joined by adhesives in presses. The bonding of the wood veneers is taken orthogonally with the objective of increasing the dimensional stability of the panel, as described by Watai (1987). According to Iwakiri et al. (2012), one of the species of wood used for the production of plywoods are, principally, the species of the genus *Eucalyptus sp.* and *Pinus sp.*

Tomaselli (1998) classified the plywood panel according to their use in: internal use plywood, glued with urea formaldehyde resins; plywood for the use of external use, glued with phenol formaldehyde resins.



In furniture industry, the use of quality plywoods is a fundamental requirement. However, to maintain the quality of plywood, Iwakiri (2005), commented that the process of gluing the wood veneer, which form the plywood, must be strictly controlled. To maintain quality during the gluing process. Iwakiri (2005) recommends the following variables control: formulation of the adhesive, thickness of wood veneer and pressing cycle parameters (temperature, pressure and time of pressing).

Vick (1999), Frihart (2005) and Frihart and Hunt (2010) reported that the process of glue is influenced also by the anatomical, physical, chemical and mechanical properties of wood.

Due to large amount of factors that can affect bonding of the plywood and compromising its quality, a strict control of the properties of these panels is required. For analysis of physical and mechanical properties of plywood panels, some authors have used the traditional statistic (Bortoletto Júnior and Garcia (2004), Arruda *et al.*(2013), Albino *et al.* (2015)). However, despite its importance, the use of traditional statistic is not sufficient to analyze the variations that can occur in all regions of the panel.

A method used to analyze the changes in a particular region and between regions is the geostatistics method. Geostatistics is a name associated with a class of techniques used to analyze and infer values of a variable distributed in space and/or time (CAMARGO, 1997). In this way, the analysis of the panel properties, involving the method of geostatistics, enables higher understanding of their variability and assists in the identification of the causes of the defects, ensuring the quality of the product.

In this context, the present study aims to assess the variability of physical properties in the entire size of the plywood panel *Eucalyptus sp.*, using geostatistics.

2. MATERIAL AND METHODS

2.1. Plywood panels preparation

Three plywood panels, composed of five layers, were produced. To make the plywood panels were used woods veneer of *Eucalyptus sp.* and polyurethane single component adhesive "supertackplus".

Woods veneer, employed in the manufacture of panels, had an average thickness of 3.32 mm and were squared in 40 x 40 cm. Squaring of the wood veneer was conducted in the Wood Machining Laboratory (UNESP, campus of Itapeva- SP). The production of the panels was held at Wood Processing Laboratory (UNESP, campus Bauru).

The average weight of the adhesive used for gluing the wood veneer was 427g /m² on each double glue line (bonding pressure: 1:47 MPa). Table 1 shows the conditions and characteristics of manufactured panels.

Table 1: Conditions and characteristics of the plywoods.

	Panel 1	Panel 2	Panel 3
Mass without adhesive (g)	1500	1490	1480
Mass with adhesive (g)	1770	1750	1770
Amount of adhesive on the panel (g)	270	260	290
Glue lines	4	4	4
Area of each layer (m ²)	0.16	0.16	0.16
Grammage per double glue line (g/m ²)	421.88	406.25	453.13
Mass after pressing (g)	1730	1690	1730
Temperature (°c)	90	90	90
Pressing time (min.)	25	25	25

Source: author.

Four weeks after its manufacture, the panels were squared on the dimensions of 350 x 350 mm and samples were taken for testing of characterization of physical properties: specific mass, moisture content and water absorption, as shown in Figure 1.

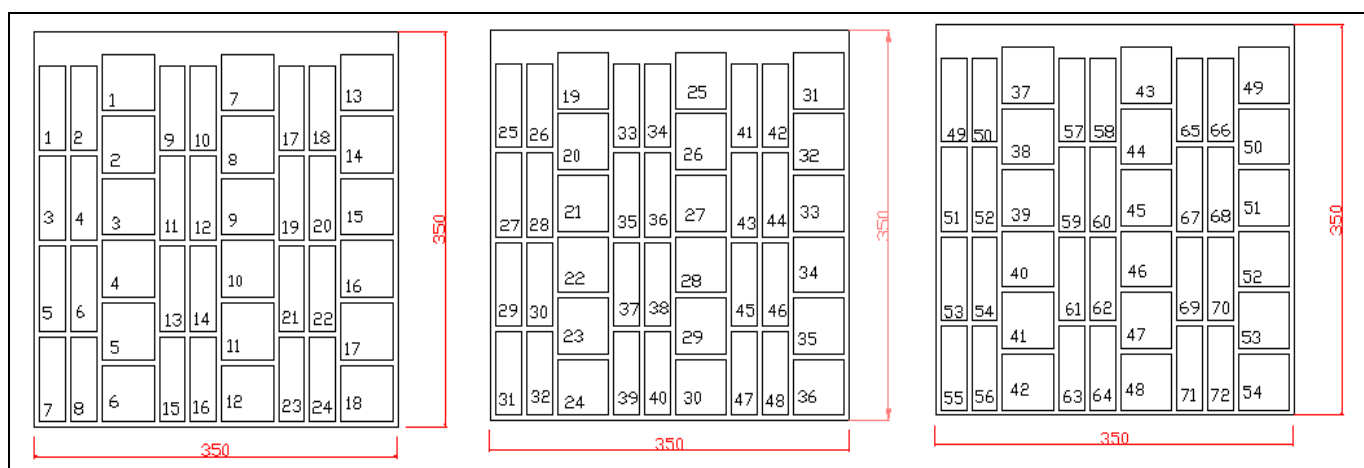


Figure 1: Specimen layout on the panels (mm).

Source: author.

2.2. Characterization of plywood panels

For the physical characterization of the panels were employed with standards EN 323-2000 (determination of specific mass), EN 322-2000 (determination of moisture content) and standard ABNT NBR 9486-2011 (determination of water absorption).

2.3. Statistical analysis

Statistical analysis was done using the geostatistics method. According to Ribeiro Júnior (1995), the geostatistics does not refer to a special type, different or alternative of statistics. In geostatistics, samples are described by its value as a function of its position in a coordinated data system. This method characterizes the spatial distribution, differing locations with higher aggregation of individuals of the localities with less aggregation and also the areas devoid of individuals (LIMA *et al.*, 2006).

Camargo (1997) described the study involving geostatistics techniques must follow some steps: (1) exploratory analysis of the data; (2) structural analysis (calculation and variogram modeling); and (3) realization of inferences (kriging or simulation).

For Huijbregts (1975) apud Camargo (1997), the variogram is a basic technical support tool of kriging, that allows you to represent the variation of a regionalised phenomenon in space. For Camargo (1997) it is necessary to fit a model for the estimates obtained from the "kriging" are more accurate and therefore more reliable.

According to Delfiner and Delhomme (1975), the factors that differentiate the "kriging" of other interpolation methods are: the estimate of a spatial covariance matrix that determines the weights assigned to the different samples; the treatment of data redundancy; the neighborhood to be considered in the inferential procedure; and the error associated with the estimated value. In addition to these factors, the "kriging" also provides accurate estimators with no bias and efficiency properties.

Camargo (1997) mentioned that among the models most used in geostatistics are the potential model, spherical model, exponential model and Gaussian model, as shown in Figure 2.

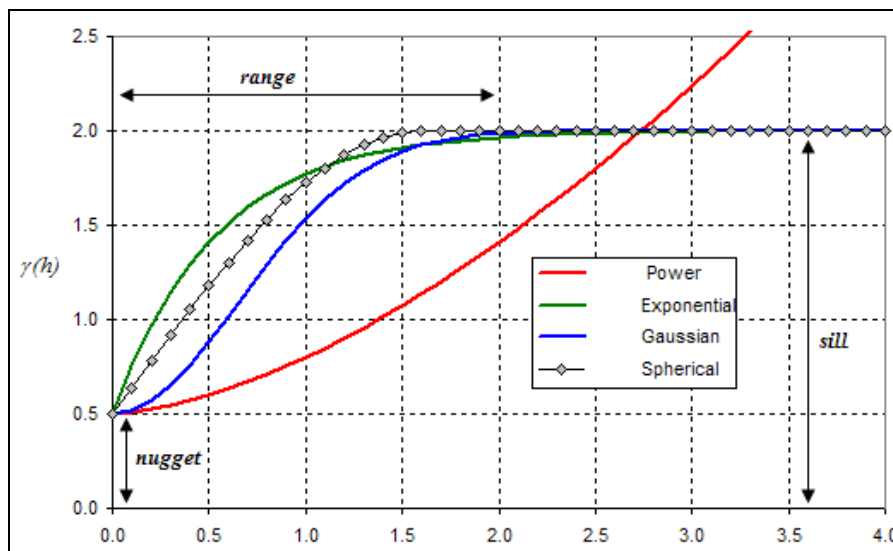


Figure 2: Semivariogram example: parameters and models employed.

Source: adapted from: <http://xongrid.sourceforge.net/>

In Figure 2, are also showed the semivariogram parameters:

- Range: distance within which the samples are spatially correlated.
- Sill: is the value of the semivariogram corresponding to its range. From this point on it is considered that there is no more space dependence between samples, because the variance of the difference between pairs of samples does not vary with the distance.
- Nugget: Reveals the discontinuity of the semivariogram for distances smaller than the small distance between samples.

The parameters for modeling the behavior of the samples were calculated with the aid of the geoR software, which is a free software environment for statistical computing and graphics. According to Ferreira (2013) R program is one of the best to existing statistical analysis today. All the console window contents can be saved, checked and eliminated using Windows and Toolbar resources. A widespread way to use R is type programs and macros that will run in a window called script. The main advantages of R is the fact of being a free program, and packages (libraries / packages) are written and developed by researchers from different areas of knowledge. Among the packages, it stands out the geoR used for geostatistical analysis.

3. RESULTS AND DISCUSSIONS

3.1. Plywood panel characterization

The apparent density of the plywood panels of *Eucalyptus sp.* was $652.09 \pm 6.31 \text{ kg/m}^3$. The moisture content was $10.66 \pm 0.27 \%$. The percentage of absorbed water was $50.50 \pm 1.23 \%$. In table 2 were shoed values found in the literature for moisture content, specific mass and water absorption.

Table 2: Comparative summary of the values obtained on this work and literature.

Source	Specie	Adhesive	Specific mass (kg/m ³)	Moisture content (%)	Water absorption (%)
This work Bortoletto	<i>Eucalyptus sp.</i>	Polyurethane	$652.09 \pm 6,31$	10.66 ± 0.27	50.50 ± 1.23
Júnior (2003)	<i>Eucalyptus sp.</i>	Phenol formaldehyde	767- 973	9.18- 10.24	17.51-36.79
Almeida (2002)	<i>E. grandis</i>	Urea formaldehyde	680	10.55	38.85
Almeida (2002)	<i>E. urophylla</i>	Urea formaldehyde	640	11.11	43.76
Kollmann (1975)	–	–	550	7.30- 12.70	–

Source: author.

The results of specific mass and moisture content, obtained from this work, were very similar to those found in the literature.

The water content absorbed was 7% higher than that obtained by Almeida (2002), which was of 43.76%. Possibly, the high water absorption in the plywood panels is associated with the surfaces conditions of the veneers of *Eucalyptus sp.*, which were with some cracks.

3.2. Variability analysis of the samples in the panel

The variability analysis of the samples in the panel was performed using the concepts of geostatistics. The variation of the regionalised phenomenon in space was quantified through the semivariogram.

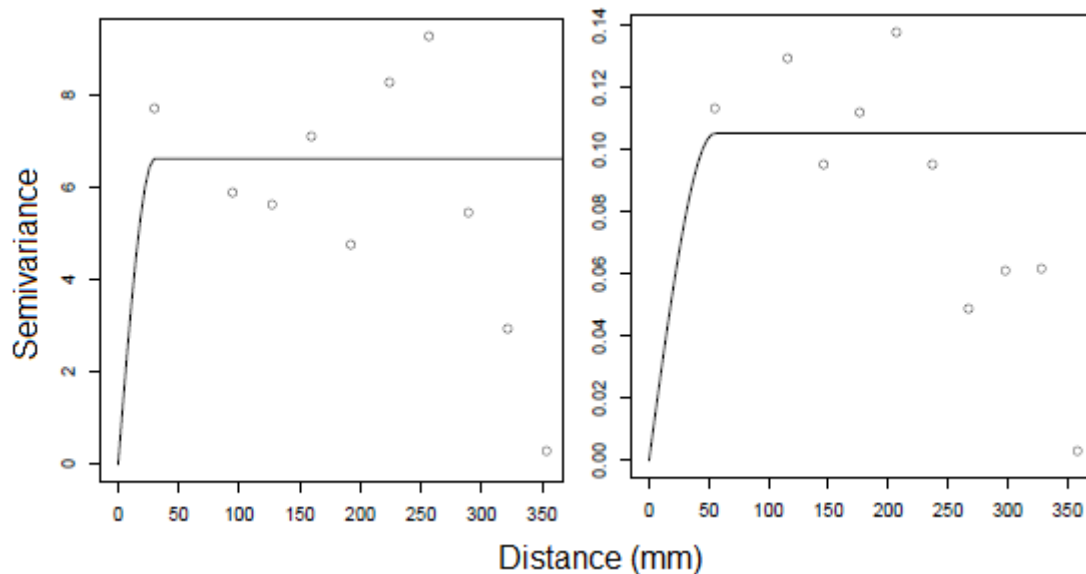
First, the parameters for modeling the behavior of the samples in the semivariogram were calculated and showed in Table 3.

Table 3: Samples modeling parameters.

Properties	Nugget effect	Sill	Range	Least square
Moisture content	0.00	0.11	55.00	0.13
Specific mass	42.78	247.09	218.63	707,945.40
Water absortion	0.00	66.11	30.00	811.31

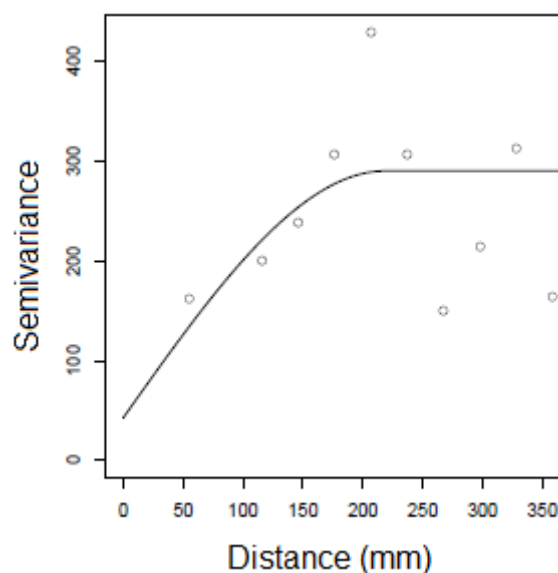
Source: author.

From the parameters showed in Table 3, the semivariogram was constructed for water absorption, moisture content and specific mass, as Figures 3 (a), 3 (b) and 3 (c), respectively. The semivariograms curves were adjusted by the method of least squares.



(a)

(b)



(c)

Figure 3: Semivariograms to: (a) water absorption; (b) moisture content; (c) specific mass.

Source: author.

With behavior of the semivariogram and the kriging method was possible the interpolation and extrapolation of results at certain points of the Panel to the other regions.

In figures 4 (a), (b) and (c) it is possible to observe the behavior of the samples for water absorption, moisture content and specific mass, respectively. The behavior of the samples is represented by the level curves of the properties and their extrapolations.

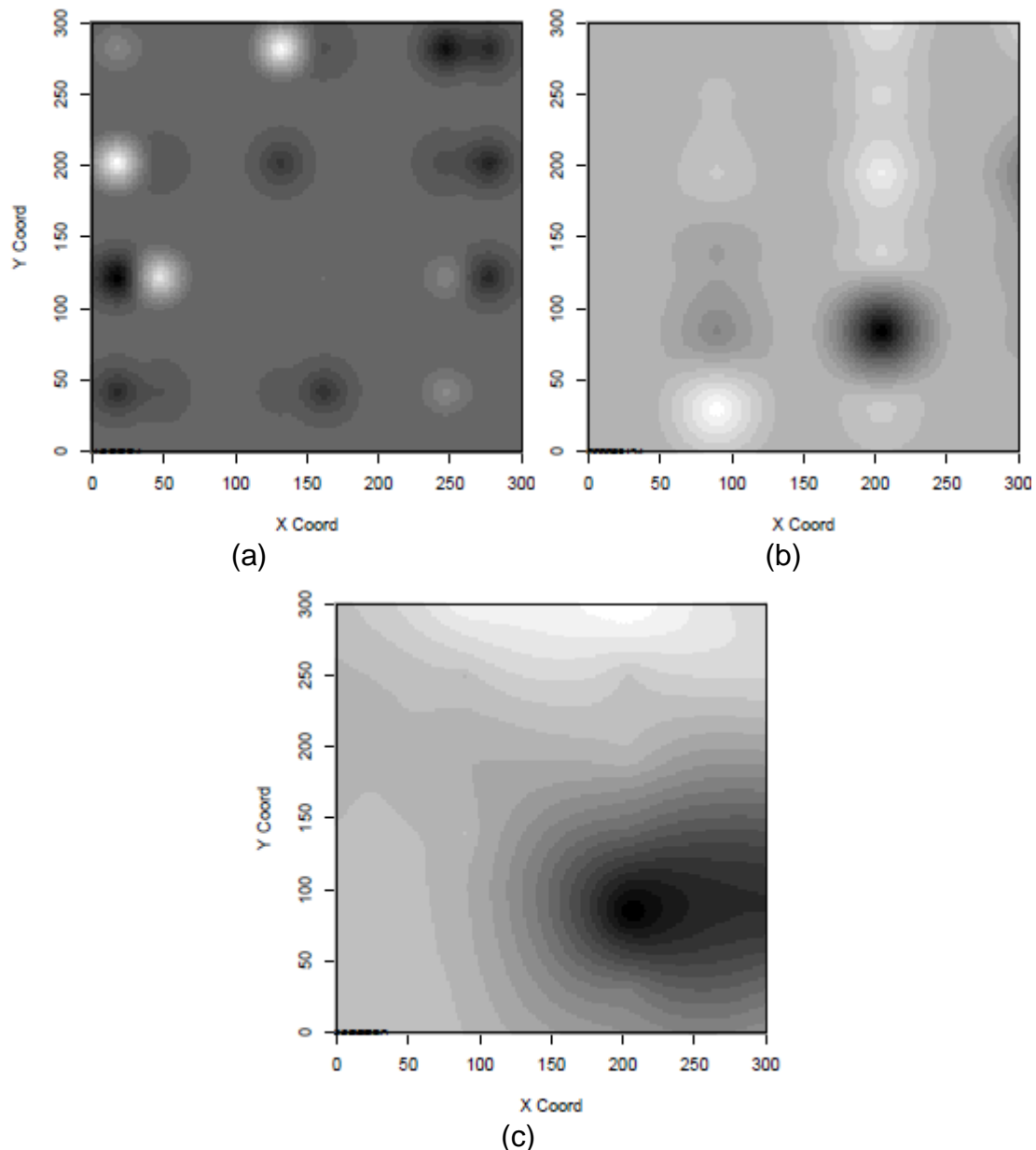


Figure 4: Samples behavior: (a) Water absorption samples behavior; (b) Moisture content samples behavior; (c) Specific mass samples behavior.

Source: author.

In Figure 4 (a) it is possible to observe the existence of areas with darker points. These points correspond to the places of higher absorption of water. Alongside these points are located the curves of levels, which are the extrapolations from measured values for the property "water absorption". This staining pattern

occurred in at least seven points in the panel, and almost always on the edges. Two possible explanations for this pattern of behavior are related to surface cracking and movement of the adhesive. The adhesive can have migrated to areas with surface cracks, leaving gaps in the line of glue fill, which favored the absorption of water. Another possibility is the adhesive drive towards the edges, through the action of pressing and temperature. Adhesive drive facilitates their evaporation and subsequent absorption of water. The evaporation of the adhesive can be confirmed by measurements of the panels mass (Table 1). The panel 2, for example, lost about 60 g of adhesive. The points of lighter color, in Figure 4 (a), represent the sites of low water absorption.

In Figure 4 (b) was presented the behavior of the samples for the moisture content. The darker regions correspond to the higher moisture content and lighter regions represent the lower moisture content.

The behavior of the specific mass along the panel can be displayed in Figure 4 (c). The darker region represents the higher points of specific mass.

Comparing Figures 4 (b) and 4 (c) it is observed that, the region of higher moisture content value corresponded to the maximum specific mass region. According to Almeida (2002), the moisture content influences the specific mass of the panel, which explains the result.

May have occurred the accumulation of wood veneer with larger thicknesses, in the region of higher density and moisture content of the panels. The accumulation of wood veneer may result in increased wood density, during the pressing process.

Almeida (2002) mentioned that the resistance of the plywood panel is directly linked to the thickness of the wood veneer. Wood veneers with heterogeneous thickness can result in regions of higher pressing pressure, causing differences in the amount of glue, which impairs the degree of adherence of the wood veneers, which may occur the so-called "bonding failure".

The variability found in the panels can also be related to manufacturing process parameters such as temperature and pressure.

The values of the temperatures and pressures used in the press have followed the recommendations of specialized literature. However, may have been a

non-uniform distribution of temperature and pressure on the surface of the press, causing several anomalies along the entire area of the panel.

The behavior of the three analyzed variables (moisture content, specific mass and water absorption), did not reach the desired expectations, because these properties should have uniformity within the plywood panel. Unlike the expected result, the plywood panels showed large variations of its physical properties.

4. CONCLUSION

The average values of the water absorption were 7% higher compared to other papers. Thus, these panels can only be applied indoors.

The average moisture content and specific mass were within the average values found in the literature.

The behavior of the properties analyzed by geostatistical model does not present homogeneity, undermining the possible application of plywood in the manufacture of furniture products.

Possibly the lack of homogeneity of the analyzed properties, can be related to undesirable variations in the used pressure and temperature parameters. The values of the temperatures and pressures used in the press have followed the recommendations of specialized literature. However, may have been a non-uniform distribution of temperature and pressure on the surface of the press, causing several anomalies along the entire area of the panel.

The behavior of the properties analyzed by geostatistical model does not present homogeneity, undermining the possible application of plywood in the manufacture of furniture products.

The method of analysis by geostatistics technique seems to be suitable for the study of the properties of the plywood panels and it can be applied for better quality control.

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