

Communication

Hardness and Roughness of Overlaid Wood Composites Exposed to a High-Humidity Environment

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Abstract: The objective of this experimental study was to evaluate the surface roughness and hardness of laminated wood-based composite panels as a function of exposure to high relative humidity (RH). All samples were conditioned in a room having a temperature of 20 °C and a relative humidity of 65% before the tests were carried out. Surface roughness, Janka hardness and mass change rate of the raw and overlaid samples were determined before and after humidity exposure. The surface of the overlaid samples was also investigated by SEM. The stylus method was used to determine the fluctuations of the surface quality of the raw and overlaid composites. The surface quality and hardness of the samples were influenced by increases of the RH level and exposure time. The mass rate change was higher for the raw samples compared with the overlaid ones. The findings of this study can be applied to improve production techniques in furniture manufacturing and to enhance the use of overlaid composite panels.

Keywords: composite; overlaying; surface roughness; hardness

1. Introduction

Wood composites are man-made products designed for specific quality or performance requirements. These products can be made in different thicknesses, grades, sizes, and may present different degrees of exposure durability. They can be found in diverse array of applications, from industrial scale to small home projects [1–4].

Wood composites such as particleboards and medium density fiberboards (MDF) are major products for furniture manufacturing and interior design of living spaces. Particleboard and MDF are still preferred nowadays to solid wood in cabinetry applications mostly for their low cost and finishing properties in overlaying and coating [5–7]. To keep a balance between quality and low cost, manufacturers may use panels with either higher density or higher thickness, as well as high-quality resins.

Wood-based composites are hygroscopic materials changing their properties as a function of humidity. During processing and service, such composites are exposed to various changes of temperature and relative humidity which directly affect panel properties, such as thickness, surface smoothness, thermal and mechanical properties as well as formaldehyde emissions [8–11]. Under such influences the panel balance is disturbed and deviations from its initial flatness may appear affecting the overall performance of the final product [5,12].

Laminated and overlaid particleboard and MDF panels are commonly used in the furniture industry because they provide durable and decorative surfaces [13,14].

Resin impregnated decorative papers are used to produce both low-pressure laminates (LPL) and high-pressure laminates (HPL). Heat and pressure activate the resin in the impregnated paper creating

a cross-linked bond with the substrate [5,15,16]. These light weight papers have a weight between 40 and 150 g/m² and can be manufactured from cellulosic or polymer-based synthetic papers [17]. A low-pressure melamine (LPM) paper is obtained by impregnation with the thermoset resin, typically melamine which is thermally fused to a substrate, such as particleboard and MDF to form melamine boards, but it does not have any kraft paper core as those found in HPL [15,16].

Decorative panels present a low impact resistance as a drawback but have some other key benefits such as low cost, readiness for use, easy maintenance, and availability in a variety of colors and finishes, along with a range of thicknesses to suit residential and commercial applications [18–21]. It was found that these impregnated papers retard the release of formaldehyde, reduce the absorption of humidity, and have improved abrasion and weathering resistance [22–24].

The surface quality of laminated panels is determined by the size of the wood particles or fibers on the surface layer. The so-called telegraphic effect is due to the roughness of the substrate penetrating through the overlay. Low humidity conditions do not affect any properties of these panels, but under exposure to high humidity, the surface roughness of these panels will be deteriorated [7,10]. A proper control of the temperature and relative humidity (RH) in a house is healthy for both the inhabitants and the furniture within. Therefore, it is important to quantify the effect of changes in RH over a period of time on the properties of laminated panels to have a better understanding of their behavior during their service life and use.

There is a great potential for furniture production in Romania, including that of laminated furniture which is supported by residential construction works [25].

Therefore, this experimental work aims to evaluate the surface roughness and hardness of laminated wood-based composite panels produced in Romania when they are exposed to 65% and 95% RH levels. The findings of this study can be useful to enhance the manufacturing and service life of these overlaid composite panels.

2. Materials and Methods

The experiments were carried out on commercially manufactured MDF and particleboards (PB) in Romania. To consider diverse products present in the market, the particleboard samples were supplied by two different companies. Most of the PB and MDF are manufactured using formaldehyde-based adhesives, namely urea-formaldehyde and phenol-formaldehyde, which have low cost and provide panels with excellent physical and mechanical properties.

A total of 40 samples were cut in the dimensions of 95 mm × 95 mm. The samples were divided in four groups. Some samples were subjected to overlaying with melamine-impregnated paper. The overlaid and raw (non-overlaid) samples were exposed to humid conditions at a relative humidity of 95% for one and two weeks, as displayed in Table 1.

Control samples for each type of product were also tested in the established exposure conditions. Prior to any tests, all samples were conditioned for a week in a room having a temperature of 20 °C and a relative humidity of 65%.

The density of the samples was calculated by measuring the dimensions and weight at accuracy levels of 0.01 mm and 0.01 g, respectively. Table 1 displays the characteristics of the composite samples and the experimental schedule.

Table 1. Experimental schedule.

Type of Panel	Particleboard (PB)		Medium Density Fiberboard (MDF)	
	Thickness, mm	Density, kg/m ³	Thickness, mm	Density, kg/m ³
	16	780	5	836
Number	20		20	
Dimensions	95 mm × 95 mm		95 mm × 95 mm	
Category and Number of Samples	Raw-10	Overlaid-10	Raw-10	Overlaid-10
	Note: Samples were set in three groups per category as displayed below:			
	control -2	exposed for 1 week-4		exposed for 2 weeks-4

2.1. Overlaying and Humidity Exposure of the Samples

A total of 20 samples, 10 for each type were overlaid with melamine-based decorative paper weighing 120 g/m². The decorative paper was applied on both surfaces of the sample and compressed using a pressure of 2.1 MPa at a temperature of 165 °C for 75 s by employing a laboratory Carver press.

Eight overlaid and raw samples from each category and type of composite panels were placed in a chamber at a relative humidity of 95% and were kept there for one and two weeks, respectively. Two samples from each category were kept as control samples at room conditions at a temperature of 20 °C and a relative humidity of 65%.

2.2. Surface Roughness Measurement of the Samples

The surface roughness of all samples was determined before and after their exposure to humid conditions. According to ISO 4287 two roughness parameters, namely average roughness (R_a) and mean peak-to-valley height (R_z) were calculated from digital information acquired from the surface of each sample [26].

A portable surface roughness tester of SRT 6200 type equipped with a skid diamond stylus of 10 µm radius and 90° tip angle was employed for roughness measurements as illustrated in Figure 1. Eight measurements, four on each side of each sample, were taken at a constant speed of 1 mm/s over a 15 mm tracing length. The cut-off length for the test was about 2.5 mm. The calibration of the profilometer was checked every 50 measurements using a standard reference plate with a R_a value of about 1.75 µm.

**Figure 1.** Roughness tester of SRT 6200 type.

2.3. Hardness Measurement of the Samples

A Comten Universal Testing Machine was used to measure the Janka hardness. Four hardness measurements, two on each side of each sample, were randomly taken from raw and overlaid PB samples before and after the exposure to humidity.

A steel sphere with a diameter of about 11.2 mm was half-embedded onto the sample surfaces as illustrated in Figure 2.



Figure 2. Hardness measurement of overlaid particleboard (PB).

2.4. SEM Analysis of the Samples

The surface of the overlaid samples was examined by using SEM. Small samples with dimensions of 10 mm × 5 mm were cut from the control and exposed overlaid samples of MDF and PB.

They were put under vacuum and coated with a thin film of gold using an ion sputtering device, before micrographs of the surfaces were taken with a SEM device of FEI Quanta600 F type.

2.5. Processing of the Data

The Minitab 17.3.1 software was used to process all data and to compile the graphical representations as interval plots of the parameters under study at 95% confidence interval (CI) for the mean values.

In this study, the status of the samples before exposure refers to their status when kept at room conditions at a temperature of 20 °C and a relative humidity of 65%.

3. Results and Discussion

In this study, melamine-overlaid and raw MDF and PB samples were analyzed before and after exposure to humid conditions for one and two weeks.

Average roughness values of the samples and their mass change rates as a function of the exposure conditions are presented in Tables 2 and 3. The particleboard samples were supplied by two different companies and therefore some differences in the roughness values of the samples before their exposure to humidity were recorded.

Table 2. Average values of surface roughness of the composite samples before and after exposure to humidity conditions.

Type of Composite Panels			MDF		PB	
Exposure Time/Roughness Parameter	Category/Status		Raw	Overlaid	Raw	Overlaid
1 week	R_a , μm	before	6.48 (0.72) *	0.32 (0.11)	8.64 (1.35)	0.30 (0.14)
		exposed	6.75 (0.74)	0.31 (0.11)	8.75 (1.33)	0.32 (0.11)
	R_z , μm	before	18.34 (2.06)	0.93 (0.32)	24.46 (3.83)	0.85 (0.41)
		exposed	19.11 (2.09)	0.89 (0.31)	24.77 (3.77)	0.93 (0.31)
2 weeks	R_a , μm	before	6.62 (0.71)	0.36 (0.13)	7.17 (0.91)	0.31 (0.21)
		exposed	8.11 (0.98)	0.34 (0.11)	7.42 (1.12)	0.41 (0.37)
	R_z , μm	before	18.74 (2.02)	1.03 (0.37)	20.31 (2.58)	0.91 (0.62)
		exposed	22.98 (2.77)	0.97 (0.31)	20.98 (3.18)	1.18 (1.06)

* Numbers in parenthesis are standard deviation values.

Table 3. Rate of mass change of the composite samples after exposure to humidity conditions.

Type of Composite Panels/Category		MDF		PB	
Mass Change/Exposure Time		Raw	Overlaid	Raw	Overlaid
Mass change, %	After 1 week	5.98	3.17	4.02	2.25
	After 2 weeks	10.67	5.33	7.38	6.13

The average values of the surface hardness of the raw and overlaid PB samples are also summarized in Table 4.

Table 4. Average values of hardness of the particleboard samples before and after exposure to humidity conditions.

Type of Composite Panel			PB	
Exposure Time/Janka Hardness	Category/Status		Raw	Overlaid
1 week	HJ, pounds	before	796.1 (76.30) *	931.3 (48.90)
		exposed	576.0 (61.40)	748.94 (25.91)
2 weeks	HJ, pounds	before	757.8 (67.70)	938.75 (36.12)
		exposed	562.0 (44.00)	653.56 (29.71)

* Numbers in parenthesis are standard deviation values.

Interval plots at 95% CI for the mean values of the roughness parameters for raw and overlaid samples are displayed in Figures 3 and 4, and Figures 5 and 6, respectively.

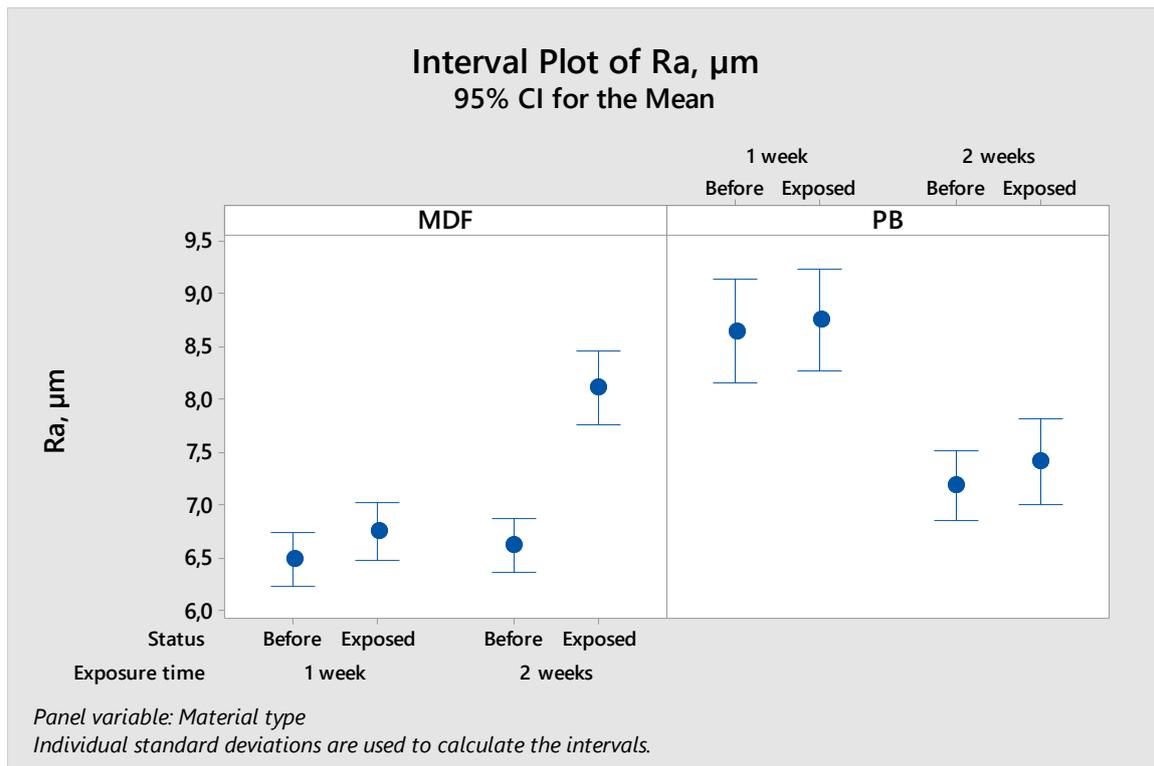


Figure 3. Variation of the average roughness parameter (R_a) of the raw MDF and PB samples, before and after exposure to humidity conditions.

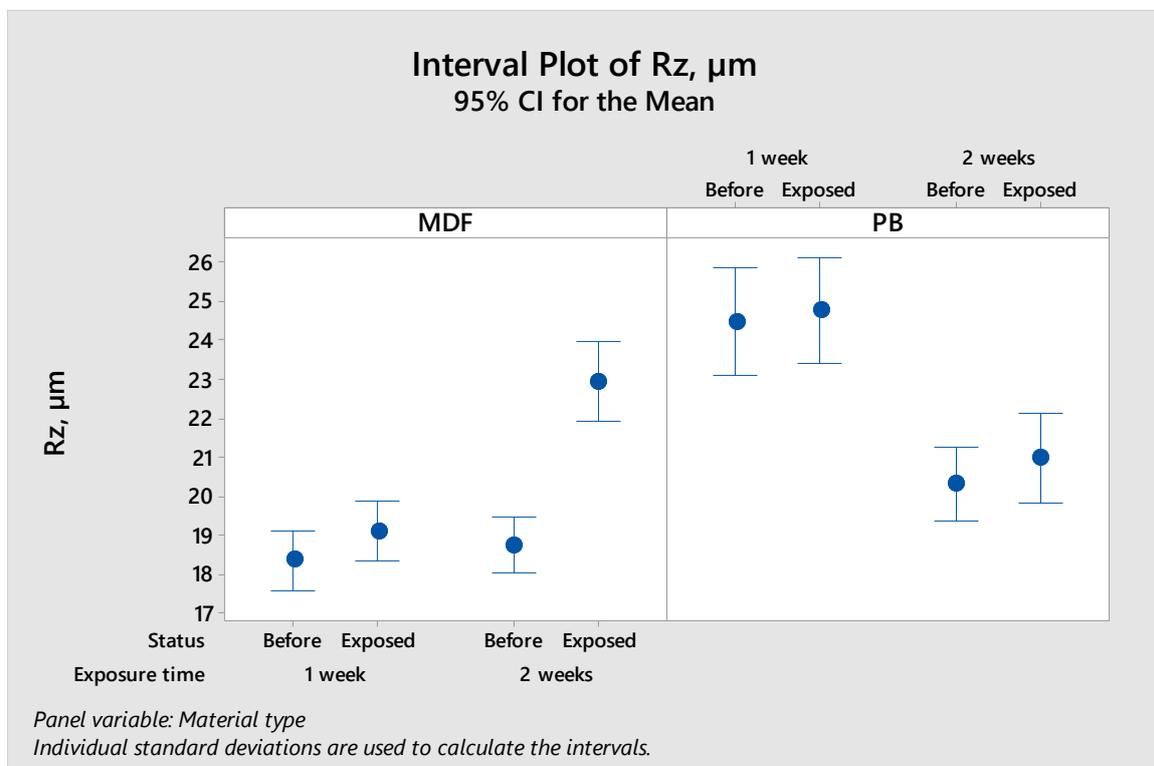


Figure 4. Variation of the mean peak-to-valley height parameter (R_z) of the raw MDF and PB samples, before and after exposure to humidity conditions.

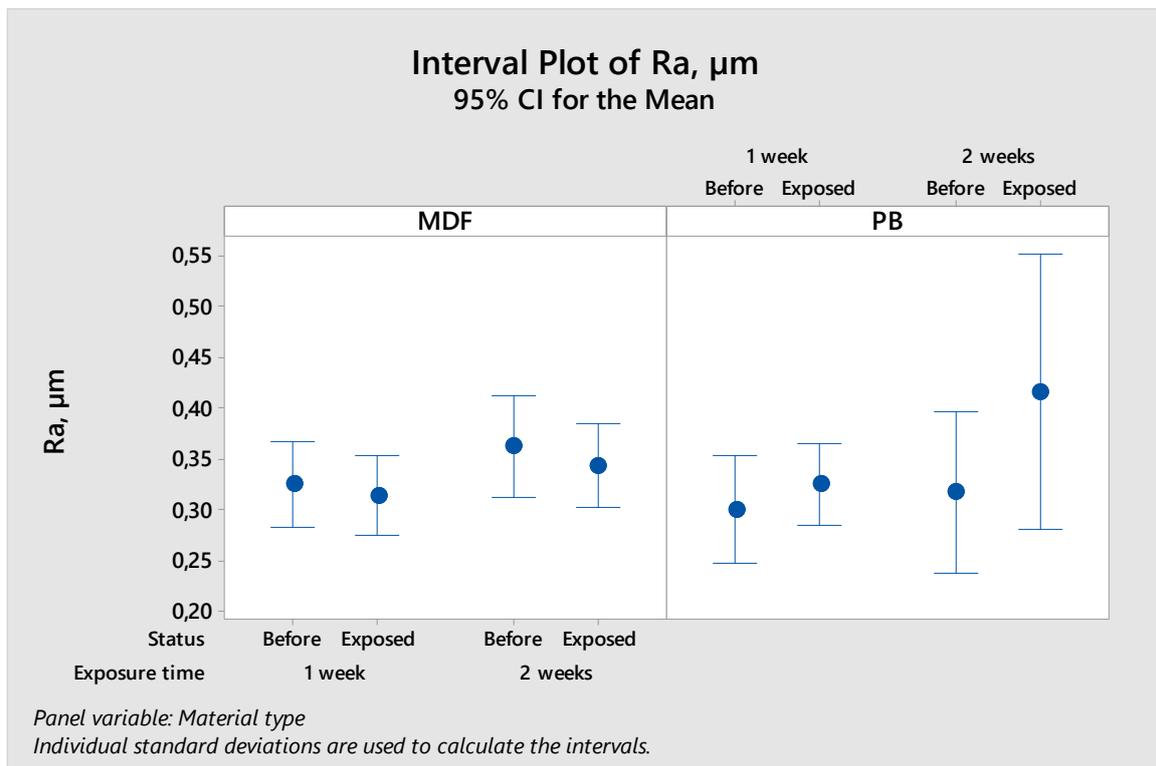


Figure 5. Variation of the average roughness parameter (R_a) of the overlaid MDF and PB samples, before and after exposure to humidity conditions.

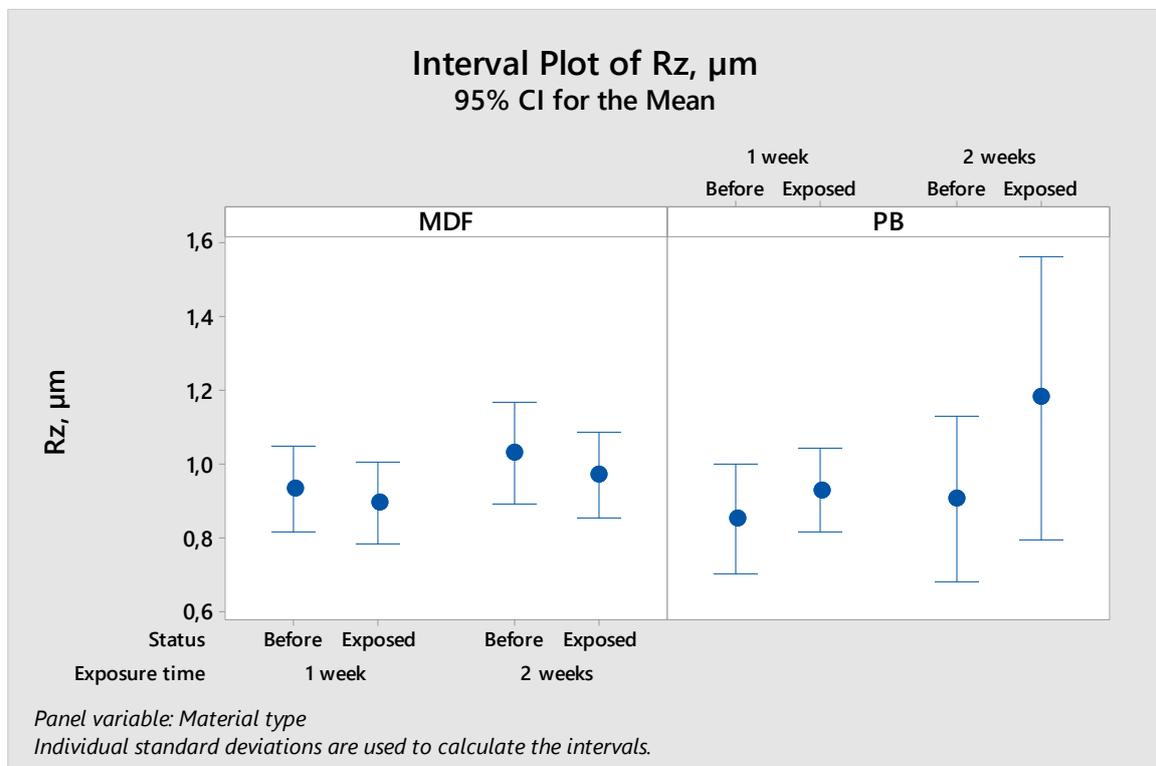


Figure 6. Variation of the mean peak-to-valley height parameter (R_z) of the overlaid MDF and PB samples, before and after exposure to humidity conditions.

Figures 7 and 8 depict the graphical representations as interval plots at 95% CI for the mean values of hardness of the raw and overlaid PB samples, respectively.

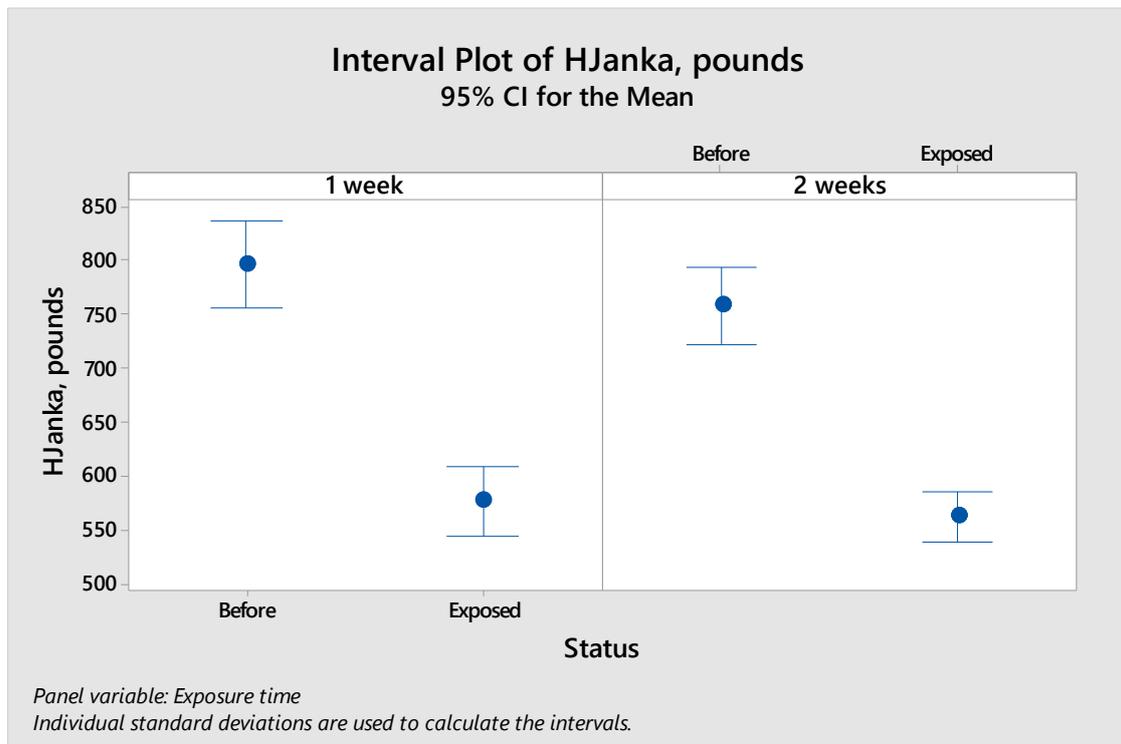


Figure 7. Variation of the Janka hardness of the raw PB samples, before and after exposure to humidity conditions.

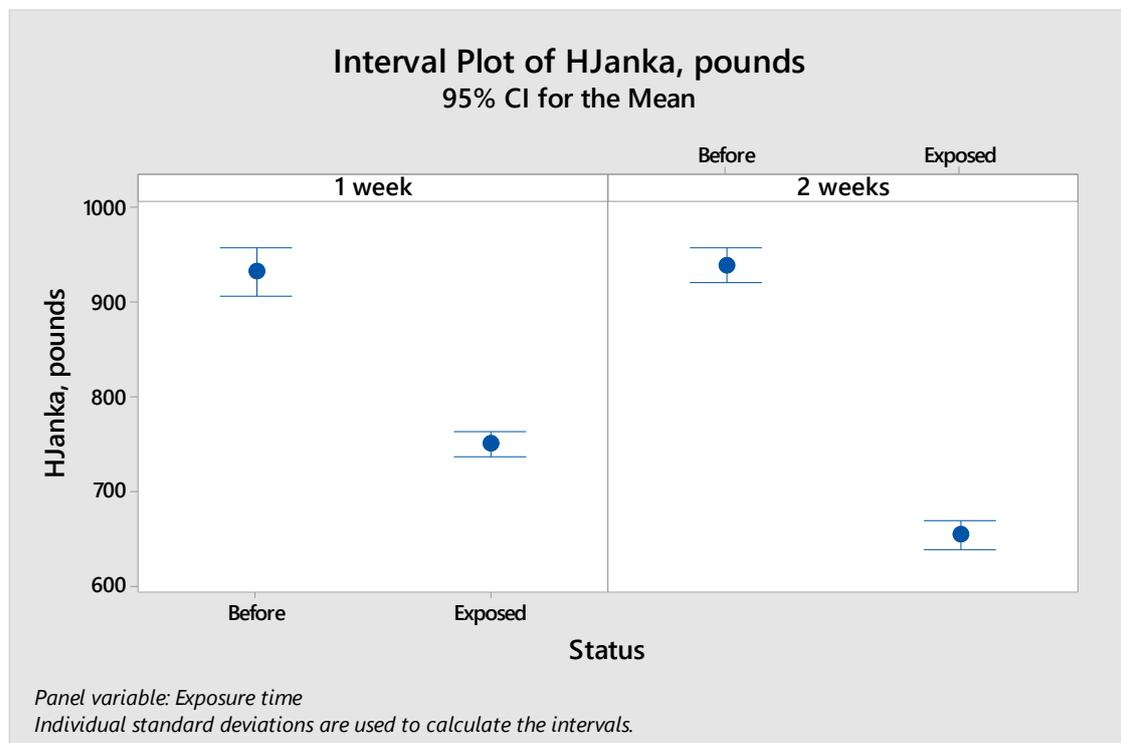


Figure 8. Variation of the Janka hardness of the overlaid PB samples, before and after exposure to humidity conditions.

3.1. Evaluation of Surface Roughness and Mass Change of the Samples

As expected both roughness parameters of the raw surfaces increased as a result of exposure to humidity as can be observed in Figures 3 and 4. However, very small changes in the roughness parameters were noticed after one week of exposure to 95% RH.

In the case of the raw MDF samples, two weeks of exposure to humidity affected significantly the roughness of the samples. Increases of the roughness parameters corresponding to 22.50% for R_a and 22.40% for R_z were noticed for the raw MDF samples after two weeks of exposure compared to irrelevant differences in roughness of about 3.48% and 3.29% obtained for raw PB.

In a previous study similar values were found in terms of surface quality of non-overlaid PB made of redcedar and exposed to different relative humidity levels for 10 days [7]. In this study, the R_a values of the samples varied from 8.24 to 10.99 μm when the humidity level increased from 60 to 95%RH.

In the case of the overlaid samples, little changes were recorded in terms of surface quality for both exposed and control samples compared to raw specimens, as shown in Figures 5 and 6. Such difference could be due to the protective surface of the overlay against relative humidity.

The roughness of the overlaid MDF samples did not change during humidity exposure. Very similar average values of R_a and R_z were determined at both exposure times. However, considering the median values of R_a and R_z , it appeared that the roughness of the surfaces slightly increased after two weeks of exposure, as indicated by the values of the two parameters, changing from 0.31 to 0.32 μm and from 0.88 to 0.90 μm , respectively.

Hiziroglu and Suzuki [10] found that overlaid MDF made of sugi and hinoki wood showed a similar increase in the R_a values, from 0.61 to 1.25 μm , when the samples were exposed to 55% and 93%RH for three months.

The results showed that all the surface roughness values of overlaid PB increased after both exposures to a humid environment of 95%RH. However, one week of exposure produced little change of the surface quality of these panels, and R_a and R_z increased by 6.6% and 9.4%, respectively. Two weeks of exposure influenced much more the roughness results, as shown by R_a and R_z increase of 32.2% and 29.6%, respectively. Hiziroglu and Suzuki [10] also found significant changes in the roughness values of R_a , varying from 0.68 to 1.5 μm for overlaid PB made of sugi and hinoki wood.

In regard to the mass change rate, an increase was found along as the exposure time to humidity increased for all four categories of samples (Table 3). As expected, the mass change rate was higher for the raw samples compared to the overlaid samples at the same time of exposure to humidity. PB panels were more resistant to mass change compared to MDF samples. The raw MDF samples exposed to humidity for two weeks were characterized by the largest mass change rate corresponding about 10.67%.

3.2. Janka Hardness of the Samples

Exposure of the PB samples to high relative humidity will make them softer, and thus their hardness values are expected to be reduced. Therefore, the values of Janka hardness of all PB samples decreased after exposure to humidity. The hardness of the raw samples was reduced by 27.64% and 25.83% after one and two weeks of exposure, respectively. This result shows that the period of exposure had no influence on the hardness of the raw PB samples (Figure 7). Initial average hardness values were found in the range of 796.12 to 757.75 pounds, and after one and two weeks of exposure, they were reduced to 576 and 562 pounds, respectively. The overlaid PB samples presented higher hardness values than the raw samples (Figure 8). This could be attributed to the brittleness of the overlay paper. However, the hardness of overlaid PB was reduced by 19.58% and 30.38% after one and two weeks of exposure at 95% RH, respectively. Values in the same range were found for overlaid PB made of sugi and hinoki wood [10]. For overlaid PB made of redcedar and exposed to humidity levels of 60% and 95%, relatively low hardness values from about 440 to 375 pounds were found, different from the values found in this study. Such differences are due to the single-layer configuration of redcedar PB [10]. The results of this work are in accordance with those of the specialty literature regarding

raw and overlaid MDF samples made of various species and exposed to different relative humidity levels [7,10]. The properties of the samples changed as a function of the relative humidity exposure, and this is related to the hygroscopic nature of wood and wood-based materials. Once humidity penetrated the samples, even for a short exposure time, the degradation of the samples was inevitable, resulting in changes of both physical characteristics and mechanical properties.

3.3. SEM Micrographs of the Samples

Overlay papers were used to cover the composite samples. Upon exposure to high RH% level, a certain separation between the overlay and the substrate is expected to take place. Figure 9 presents the SEM micrographs of the overlaid samples exposed for two weeks to 95% RH. The samples tested in this study did not show any delamination or separation either from the overlays or within the panels as a result of high humidity exposure.

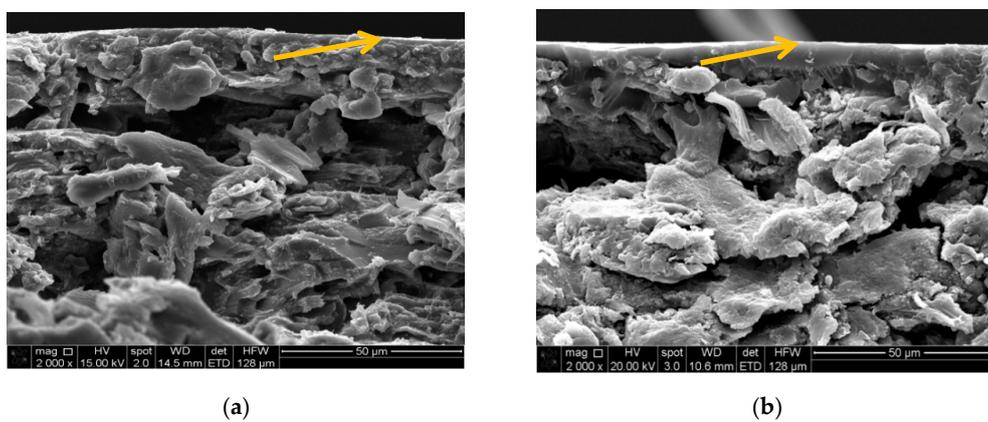


Figure 9. SEM micrographs of exposed overlaid samples (melamine layer on the top): (a) exposed MDF; (b) exposed PB; (yellow arrows indicate the borderline between the overlay and substrate).

4. Conclusions

In this study, the stylus method was used to determine the fluctuations of the surface quality of raw and overlaid composites. The surface quality of the raw and overlaid MDF and PB samples was influenced by increases in RH and exposure time. The raw MDF samples presented rougher surfaces after two weeks of exposure to humid conditions compared with the raw PB samples.

The surface quality of the overlaid MDF samples did not change much after exposure to humidity, while in the case of overlaid PB, some differences in terms of surface roughness were noticed. The mass change rate of the samples increased with the increase of the exposure time to a humid environment.

The mass change rate was higher for the raw samples compared to the overlaid ones. However, the PB samples were more resistant to mass change than the MDF samples. The overlaid PB samples presented higher hardness values than the raw PB samples due to the brittleness of the overlay paper. The increase in RH adversely influenced the overall hardness values of the PB samples. No delamination or separation, either from the overlays or within the panels, as a result of high humidity exposure was found.

The findings of this study can be applied to improve production techniques in furniture manufacturing and to enhance the use of overlaid composite panels.

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