Variables Influencing the Production of Door Jambs from *Pinus taeda* EGP Panels

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The influence of coverslip width and the physical arrangement of growth rings were studied relative to laterally glued *Pinus taeda* wood panels (EGP) used in the manufacture of door jambs, according to the requirements of ABNT-NBR 15.930 (2011). The goal was to determine the combination providing the best physical performance of the product. The experiments used the complete factorial design for two factors and four levels, *i.e*., 32, 56, 75, and 112 mm width coverslips, and rings arrangement of radial, tangential, cross coverslips, and ones with finger joints. A total of 48 EGP door jamb specimens (3 for each combination) measuring 2120 x 220 x 32 mm, with moisture content between 8% and 12% and apparent density between 400 and 600 kg.m^{-3} were used. Statistical analysis of variance (ANOVA) was used to investigate the influence of factors and their interactions on the following responses: visual aspect, moisture, density and dimensional (width and thickness) variations. It was found that both factors and their interactions influenced the level of significance of 1% on shape deviations. The best results were for panels produced with 32 and 56 mm coverslips, with cross or radial arrangement.

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INTRODUCTION

França *et al.* (2020) noted the importance of the wood industry's search for alternatives and highlighted the production of reconstituted panels for better use of the material. Among them, Edge Glued Panels (EGP) was highlighted, mainly for civil construction, floors, and doors. In this way it is possible to use pieces of wood with small defects that otherwise would be discarded, thus increasing the efficiency. França *et al.* (2020) also highlighted the importance of investigating the physical and anatomical properties that influence the EGP product. Such characteristics determine the quality of the material as well as the choice of adhesive and the connection between the battens. Thus, further studies on the production of this panel are necessary to ensure the best performance in its applications. Sedlecky (2017) emphasized the superiority of EGP in relation to other panels such as MDF, as it presents characteristics similar to solid wood and indicates the importance of the density of this material.

Many companies use laterally glued panel, *i.e.* EGP, in the production of finished door kit jambs, which characterize them as solid wood products. Others, however, are using plywood or Medium Density Fiberboard – MDF panel, as EGP panel does not achieve minimum performance to meet current standards. The concern for finished door kit manufacturers is that their kits are approved in the physical tests required by ABNT-NBR 15930 (2011). EGP *Pinus* panel jambs manufacturers are not aware of how to work the best combination of productive variables, such as wood moisture, coverslip width, adhesive weight, bond pressure, slats arrangement, and press time, among others. Having finished door kit jambs certified and attending the main requirement of ABNT-NBR 15930 (2011), they cannot suffer large dimensional variations after packaging (which simulates the day-to-day product); that is, no warping, either bending and curving, no any apparent cracks, within certain maximum limits. Therefore, it is necessary that EGP jamb manufacturers understand the variables of the production process in order to achieve the best panel composition, that is, minimization of dimensional variations of the product to meet the mininum requirements of ABNT-NBR 15930 (2011).

The alternative materials used for the manufacture of door jambs are MDF, solid wood, PVC, and plywood. The choice of EGP in this experiment is that among the possibilities, this panel presents a better combination of operational energy cost (uses less energy than other types of wooden panels) combined with better dimensional stability. The choice for *Pinus elliotti*, on the other hand, is because it has lower content of extractives, facilitating surface finishing, although *Pinus elliottii* has greater mechanical resistance and high content of extracts that can migrate and hinder the bonding of coatings.

Therefore, it is important to research the best combinations of these variables and the amount of interference with those undesired dimensional variations; the best moisture contents to work with and the best coverslips width, minimum and maximum. It´s also critical to rate the most appropriate direction, radial or tangential, and the best arrangements for wood growth rings. These doubts are present in the industrial day-to-day; therefore, research is necessary.

The physical properties of anisotropic materials depend on the crystallographic direction in which the measurements are made (Callister 2012). This characteristic is associated with the difference in atomic or ionic spacing.

The anisotropy of the wood is associated with its three cutting planes: axial (or longitudinal), tangential, and radial. Determining the main physical characteristics of wood assists in better control of its effects, as bending or curving, and is essentially what wood producers are looking for (Gonçalves 2010). ABNT-NBR 15930 (2011) is more specific about anisotropy for wood, defining this characteristic as material shrinkage, which occurs unevenly according to the directions of radial, tangential, or longitudinal growth. This can occur in the drying process, during packaging or on the product. According to Iwakiri (2005), wood logs are converted into smaller elements, wood homogeneity increases, as well as isotropy problems. Smaller pieces have smaller volumetric variations due to moisture variation. The difference in the retractibility of wood pieces after drying, as their cutting plane varies. Each piece removed from a region of the log presents different degrees of dimensional variation and warping behavior among them.

The dimensional instability of wood is the most undesirable characteristic of the wood industry (Keinert Jr. *et al.* 1992). Anisotropy limits the use of the wood, and lacking this knowledge can generate inconveniences in the quality of the product. Keinert Jr. *et al.* (1992) also studied the relationship between the contraction and the moisture content of two species of pine, *Pinus taeda* and *Pinus eliottii*. There was a direct relation between the variation of wood moisture and its dimensions. Regarding the two investigated species, *Pinus eliottii* presented lower coefficients than those of *Pinus taeda*. The behaviors of three wood species, oak, eucalyptus, and pine, in relation to moisture variation and retractions of each cutting plane.

Dimensional variation differs in relation to the directions of the wood. The swelling or shrinkage of the wood grows up to 30% moisture and above the fiber saturation point - FSP, there is no more relation of the volumetric variation with the gain or loss of moisture. The tangential shrinkage is practically twice the radial shrinkage, and the longitudinal shrinkage is negligible (Pfeil and Pfeil 2003). Trianoski *et al.* (2013) evaluated the dimensional stability of eight species of pine: *Pinus caribaea* var. *bahamensis*, *Pinus caribaea* var. caribaea, *Pinus caribaea* var. hondurensis, *Pinus chiapensis*, *Pinus maximinoi*, *Pinus oocarpa*, *Pinus tecunumanii*, and *Pinus taeda*. The radial, tangential, and volumetric contractions, as well as the specific green mass, apparent specific mass at 12%, and basic specific mass were evaluated through the collection of trees from Itararé, São Paulo state, and Ventania, Paraná state. The radial contraction was between 1.88% and 3.38%, with *Pinus taeda* showing the lowest value. For the tangential contraction, the values varied from 5.74% to 6.55%, and for the volumetric contraction, values were 8.67% and 10.64%, with *Pinus chiapensis* the lowest value in both cases. Finally, the contraction anisotropy (ratio of tangential to radial contraction) was 2.20% to 3.26%. In general, all investigated species presented medium high dimensional instability, and *Pinus chiapensis* was the most unstable species. The species with a litlle anisotropy was *Pinus taeda*, which justifies its use in the logging industries. There wasn't significant correlation among specific mass, volume contraction, and contraction anisotropy.

Tangential contraction is actually greater than the radial contraction, being almost twice as much, and that the value of the longitudinal contraction is negligible (Fig. 1). In this case, three species of wood were studied, Mahogany (*Swietenia macrophylla*), Scotch pine (*Pinus sylvestris*), and Beech wood (*Fagus sylvatica*) (Peña and Rojas 2006).

Knowing the wood anisotropy is a key factor in producing a good quality and performance EGP panel. Using wood species with a high degree of anisotropy means panel will likely warp. Wood contraction in tangential direction is greater than in its radial direction (Iwakiri 2005).

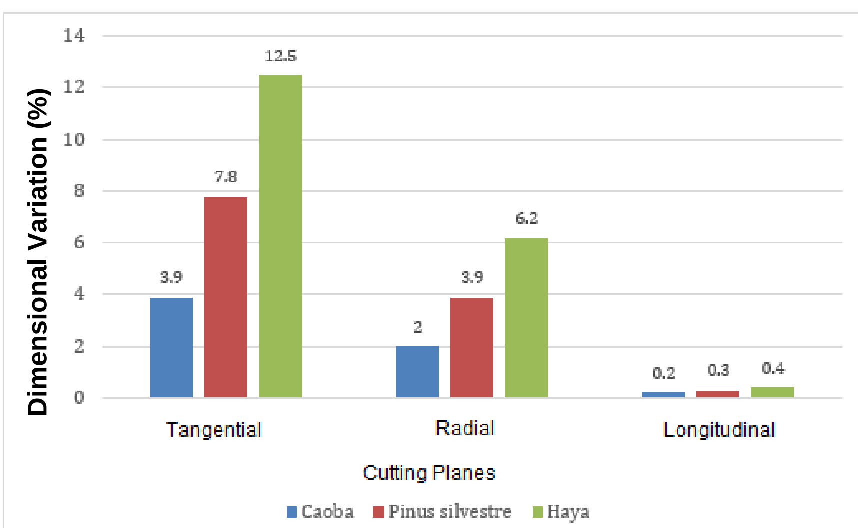

Fig. 1. Variation of the contraction in different cutting planes, Mahogany (*Swietenia macrophylla*), Scotch pine (*Pinus sylvestris*), and Beech wood (*Fagus sylvatica*). Adapted from (Peña and Rojas 2006)

Iwakiri (2005) also cites that when the slats are glued laterally to form a panel and have similar orientation to each other, panel warping, because of an increase or decrease in moisture content, is approximately four times greater than individual warping of the slats. However, when in the gluing process, this orientation is taken into account and it is done in the opposite way (distinct orientation), the panel dimensional stability presents quality. It is ideal to perform the gluing only with radial direction parts, which industrially becomes unfeasible.

Nicholls (2010) states that slats should have growth rings oriented in opposite directions; this block them from getting all the tangential slats with the same directions of the growth rings, either up or down. The lath helps to contain volumetric variations depending on the difference in moisture, gain or loss of water. Orientation of fibers it is observed in Fig. 2.

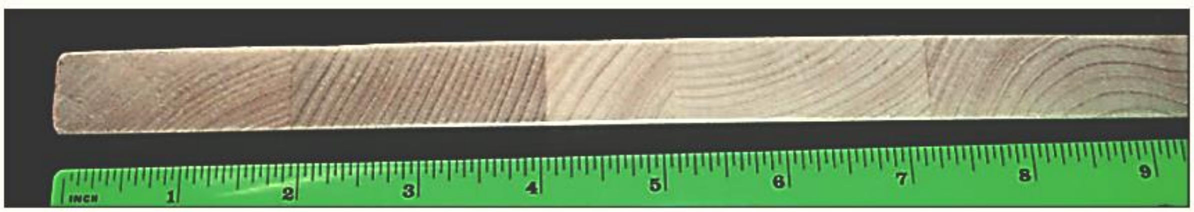

Fig. 2. EGP panel glued with slats in opposite directions. Source: (NICHOLLS 2010)

Gonzaga (2006) points out that the best layout is interspersed slats, with growth rings down and up, because in a sum of curling, they can be annulled. When the panel is formed with all the rings in the same direction, it may present warping or detachment. The author also cites four recommendations: that all slats are equally dried and from the same species; that the slats are in balance with room humidity; that smaller width slats (no values mentioned) should be used; and that low contraction rate species should be used. For Gonzaga (2006), the best scenario is the use of radially cut slats, which is not easy to execute in real circumstances.

The present work investigated the volumetric variation, density and drying of the *Pinus taeda* EGP panels used for the manufacture of door jambs (frames or staves). These characteristics are observed to determine the best combination of variables for the best physical performance of jambs and provided indications of the most appropriate forms of construction and production of EGP panel according to the specifications of ABNT-NBR 15930 (2011).

EXPERIMENTAL

Pinus taeda wood from reforestation in Sengés, Paraná state were used to make samples. The first stage of the production process of the samples was to use *Pinus taeda* boards, 2150 mm long, with apparent density in the range of 500 kg.m^{-3}, and moisture content from 8 to 12%. The coverslips were prepared according to the job demand and vary from 34 mm, 58 mm, 74 mm and 114 mm in width. These coverslips were classified for defect-free thus obtaining the radial and tangential clear coverslips.

The defective parts were uncapped and converted into blocks of 100 to 500 mm, which were joined by the finger joint process, producing long pieces of 2150 mm length called blanks. After the attainment of blanks, they were planed and glued laterally and pressed forming 2150 x 224 x 33 mm EGP panels. With this EGP, stops of dimensions 2120 x 220 x 32 mm were constructed (Fig. 3).

Then, they were subjected to moisture verification through a digital device, the Marrari M51 model, measuring 03 points, as provided by ABNT-NBR 15930 (2011), besides the measurement of apparent density. To verify the volumetric variation, they were conditioned, only once, in an air-conditioned and controlled chamber for 168 hours, with temperature and relative humidity control equal to 23 ± 2 °C and 50 ± 5%, respectively. After 168 hours, the specimens were removed from the air conditioning chamber and with the use of a caliper, the measurements of the cross section were verified. The drying defects were verified in relation to the cutting directions. Finally, they were packed with plastic and the measurements were repeated after unpacking. All data were treated statistically by Minitab v17 software.

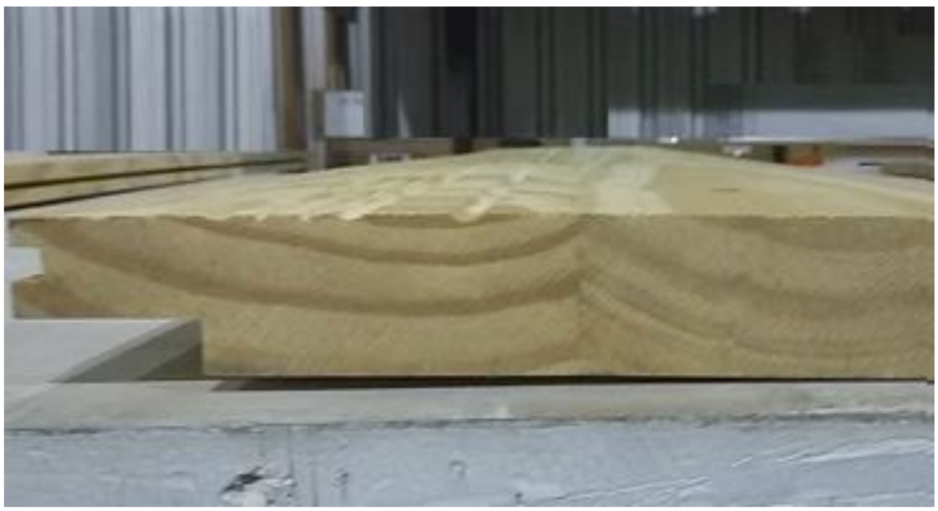

Fig. 3. EGP panel sample

RESULTS AND DISCUSSION

Moisture Content (MC)

Table 1 shows the minimum and maximum values for MC before and after packaging (MC_i and MC_f, respectively), in addition to the statistical results of the mean, standard deviation, and coefficient of variation (CV). N is the number of samples. The pieces had moisture content of 8.4% to 15.5% before packaging, an average of 11.3%. This average is within the desired range (8% to 12%), but 12 pieces presented initial moisture above 12%. After packaging, the MC ranged from 9.7% to 14.0%, with an average of 12.3%, an average increase of 1%. The minimum MC also rose from 8.4% to 9.7%, but the maximum MC decreased from 15.5% to 14.0%. When maintaining the parts in the air conditioning chamber, they reached equilibrium moisture when they changed from 11.3% to 12.3%.

It was possible to confirm with this test that by keeping the parts in the air conditioning chamber, they reached a certain equilibrium moisture content, when they changed from 11.3% to 12.3%, a fact predicted by Franzoi (1992), Gonçalves (2000), and Peña and Rojas (2006).

As for the moisture variation of the 48 air-conditioned parts, 8 of them lost moisture and the others gained. Such parts that lost moisture, had an average moisture content above 13.1%. This ability to lose or gain moisture was predicted and was cited by Peña and Rojas (2006) as hygroscopicity.

Heliodoro (2019) carried out a test comparing the EGP panel with two different adhesives and obtained a result with 3.69% and 6.11% difference between the maximum and minimum values. In Iwakiri (2018) the average values of thickness swelling ranged from 2.05% to 15.49%.

Bolgenhagen (2018) states that the volumetric retractability is a physical property of great relevance, which is responsible for the differentiated dimensional alteration of wood in the bonding and drying processes.

Table 1. Results of the Average Moisture Contents Before and After Packaging

	N	Minimum	Mean	Maximum	Standard deviation	CV (%)
MC_i (%)	48	8.4%	11.3%	15.5%	1.55%	13.64
MC_f (%)	48	9.7%	12.3%	14.0%	1.12%	9.15
ΔMC* %)	48	-1.6%	1.0%	3.4%	-	-

Note: * ΔMC = (MC_f - MC_i / MC_i). Negative ΔMC means loss of moisture. The minimum and maximum values of ΔMC were calculated taking into account the 48 samples rather than only those with the lowest and highest values.

Density Before and After Packaging

The minimum and maximum values found for ρ_a before and after packaging (ρ_{ai} and ρ_{af}, respectively) and the statistical results of the mean, standard deviation, and coefficient of variation (CV) are presented in Table 2. Bulk density ranged from 381 to 558 kg.m^{-3}, with an average of 469 kg.m^{-3}. The average is within the desired varied (400 to 600 kg.m^{-3}), but 6 pieces had density below 400 kg.m^{-3}. After packaging, the ρ_a went from 377 to 571 kg.m^{-3}, with an average of 471 kg.m^{-3}, an average increase of 0.54%. The apparent densities were in agreement with Ballarin and Palma (2003), but with CV of 10.56%, while the authors had 14.63% CV. Regarding the bulk density variation ($\Delta\rho_a$), 12 pieces of 48 samples had a decrease in density, between 0.04% and 1.52%. The others had an increase in density, in the range of 0.07% to 3.23%.

Heliodoro (2019) reached densities of 486 and 490 kg.m^{-3} in a work with pine EGP, values below the ones found in literature, as mentioned by the author. The specific density of *Pinus elliottii* wood was quite uniform during the experimental evaluation, with the mean value of 0.489 g/cm^3, while for *Pinus taeda*, the average value of 0.410 g/cm^3. The weighted density difference between species was not statistically significant in the tested sample lot (Bolgenhagen 2018).

Table 2. Results of Bulk Density Before and After Packaging

	N	Minimum	Mean	Maximum	Standard deviation	CV (%)
ρ_{ai} (kg.m^{-3})	48	380.98	468.81	558.80	47.36	10.10
ρ_{af} (kg.m^{-3})	48	376.88	471.32	571.01	49.78	10.56
$\Delta\rho_a$ (%)		-2.79%	0.49%	3.23%	-	-

Note: * $\Delta\rho_a = (\rho_{af} - \rho_{ai} / \rho_{ai})$. Negative $\Delta\rho_a$ means decrease in density. The minimum and maximum values of $\Delta\rho_a$ were calculated taking into account the 48 samples, rather than only those with the lowest and highest values.

Dimensional Variations of the Jambs

The minimum and maximum values for the width of the door jambs before and after packaging (W_i and W_f, respectively), for the variation of width (ΔW) and the statistical results of the mean, standard deviation, and coefficient of variation (CV) for these variables are shown in Table 3. When packaged, the pieces presented widths in the range of 219 to 222 mm, with an average increase of 0.41 mm, or 0.19%. This is justified by the fact that the great majority of the pieces had received moisture, thus increasing their dimensions, giving a further indication that the moisture received is the impregnation water. Comparing these width variation data with those allowed by ABNT-NBR 15930-2 (2011), all pieces were within the minimum and maximum variation limits, receiving at least the classification DV1 = 1.5 (Fig. 4).

Table 3. Results of the Jambs Widths Before and After Packaging

	N	Minimum	Mean	Maximum	Standard deviation	CV (%)
W_i (mm)	48	219.95	220.00	220.10	0.02	0.01
W_f (mm)	48	219.40	220.41	221.50	0.49	0.22
ΔW (mm)		-0.60	0.41	1.50	-	-
ΔW (%)		-0.27%	0.19%	0.68%		

Note: * $\Delta W = (W_f - W_i / W_i)$. Negative ΔW means decrease in width. The minimum and maximum values of ΔW were calculated taking into account the 48 samples, rather than only those with the lowest and highest values.

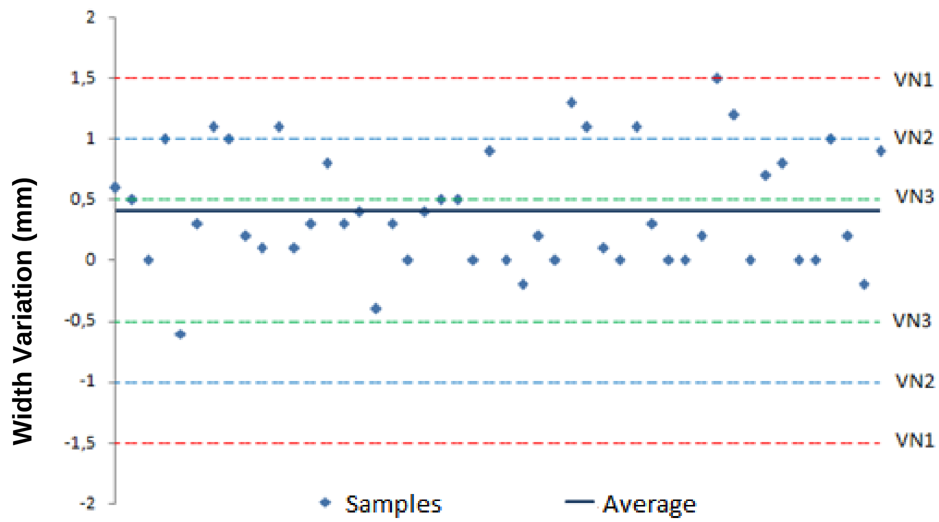

Fig. 4. Scatter plot for width variation

From the total of 48 pieces, 31 (64.58%) presented up to 0.5 mm of variation and can be considered as DV3; 10 pieces (20.83%) with width variation between 0.5 mm and 1.0 mm, classified as DV2; and 7 pieces (14.58%) with variation of 1.0 mm to 1.5 mm, considered DV1.

The analysis of variance (ANOVA) for the width variation (ΔW) occurred at climatization, in order to determine the effect of the two factors - coverslip width and rings arrangement - in an isolated way and the interaction between them (Table 3), as cited by França *et al.* (2020), in which the anatomical arrangement of the parenchyma and panels can cover the panel. The significance level of at least 10% was not reached; that is, none of these factors, alone or in combination, contributed to a width variation trend.

Table 4 shows that the factor that influenced the most in width variation was the growth rings arrangement (B), just as in the previous tests of humidity and density variation. The P-value of 0.779 shows that the level of significance is approximately 78%, well above 10%, taken as acceptable, or even the desirable 5%. As for the coverslip width (A), the P-value was 0.900, well above the acceptable limit for significance. The interaction coverslip width *vs.* rings arrangement (A x B) had P = 0.775 and F = 0.62.

Table 4. Analysis of Variance for ΔW means

Factor	DF	SS	MSS	F	P
Width (A)	3	0.2856	0.09521	0.19	0.900
Rings (B)	3	0.5356	0.17854	0.36	0.779
A x B	9	2.7169	0.30187	0.62	0.775
Residual error	32	15.6867	0.49021		
Total	47	19.2248			
R^2 = 0.1840					
R^2_a = 0.0001					

Legend: Degree of Freedom (DF); Sum of Squares (SS), Mean Square Sum (MSS), Statistic F (MSS / MSS error); Result of p-value (P); Coefficient of Determination (R^2) and Adjusted Coefficient of Determination (R^2_a)

The non-influence of these two factors on the width variation is attributed to the fact that the EGP panel width was the one that contributed the most to the contraction or swelling (decrease or increase) of the part in one, two or three dimensions, rather than the size of the coverslip and/or the physical arrangement of the slat rings. Door jambs of up to 220 mm suffered a maximum of 1.5 mm, or 0.75%, for an average increase of 1% in moisture content. Thus, with $R^2_a = 0.0001$, neither of the two factors influenced the width variation of the pieces. These values are within indices mentioned by River and Okkonen (1991).

The minimum and maximum values for the jambs thickness before and after packaging (t_i and t_f, respectively), of the thickness variation (Δt) and also the statistical results of the mean, standard deviation, and coefficient of variation (CV) for these variables are shown in Table 6. The pieces presented, after packaging, thicknesses in the range of 32.00 mm to 32.56 mm, with an average of 32.14 mm, an increase of 0.14 mm, or 0.44%. A great majority of the pieces had received moisture, increasing their dimensions, which is a further indication that the moisture received is the impregnation water. No records were found in the literature, to compare to the data of this work, of increasing or decreasing indexes of thickness for EGP panel.

Table 5. Results of the Door Jambs Thickness Before and After Packaging

	N	Minimum	Mean	Maximum	Standard deviation	CV (%)
t_i (mm)	48	31.95	32.00	32.10	0.02	0.06%
t_f (mm)	48	32.00	32.14	32.56	0.14	0.42%
Δt (mm)		0.00	0.14	0.56	-	-
Δt (%)		0.00%	0.06%	0.25%		

Note: * $\Delta t = (t_f - t_i / t_i)$. Negative Δt means decrease in thickness. The minimum and maximum values of Δt were calculated taking into account the 48 samples, rather than only those with the lowest and highest values.

The results of ANOVA analysis for the thickness are described in Table 6. Analysis of variance for the thickness variation (Δt) was carried out at climatization, in order to determine the effect of the two factors - coverslip width and ring arrangement - in an isolated way and the interaction between them. None of them reached the 10% significance level, that is, none of these factors, alone or in combination, contributed to a width variation trend.

Table 6. Analysis of Variance for Δt means

Factor	DF	SS	MSS	F	P
Width (A)	3	0.07644	0.025478	1.23	0.316
Rings (B)	3	0.02023	0.006742	0.32	0.807
A x B	9	0.10174	0.011304	0.54	0.831
Residual error	32	0.66410	0.020753		
Total	47	0.86250			
$R^2 = 0.2300$					
$R^2_a = 0.0001$					

Legend: Degree of Freedom (DF); Sum of Squares (SS), Mean Square Sum (MSS), Statistic F (MSS / MSS error); Result of p-value (P); Coefficient of Determination (R^2) and Adjusted Coefficient of Determination (R^2_a); Source: (Dias 2016)

Coverslip width (A) was the factor that most influenced the thickness variation, contrary to what was observed. However, the P value of 0.316 shows that the level of significance was approximately 32%, well above the 10% taken as acceptable or the desirable 5%. As for the rings physical arrangement (B), the P value was 0.807, well above the acceptable limit for significance. The interaction of coverslip width in relation to the ring arrangement (A x B) had P = 0.831 and F = 0.54.

The non-influence of these two factors on the thickness variation shows that regardless of the type of ring arrangement or the slats width, swelling or contraction will occur in any productive arrangement. Thus, with $R^2_a = 0.0001$, neither of the two factors influenced the thickness variation of the pieces. Bolgenhagem (2018) comments that the *Pinus taeda* species presents density for EGP panel as well as mechanical strength; however it presents a moisture variation of 7.82% to 15.16% that can influence the bonding area on the pieces.

CONCLUSIONS

1. In this study, the slat width and the physical arrangement of the growth rings did not influence the visual surface appearance of the pieces, since no part presented visual problems after packaging.
2. Also, they did not have a significant influence on moisture content variation of the pieces after packaging. The fact that the pieces changed from an average moisture content of 11.3% before packaging to 12.3% (average increase of 1%) after it, shows that the 7-day (168 hour) ventilation was efficient and uniform, since some pieces presented diminished moisture contents and others, increased ones, seeking balance.
3. The density variation of the pieces after packaging did not have a significant influence. The pieces had an average density of 469 $kg.m^{-3}$ before ventilation and increased to 471 $kg.m^{-3}$ after it; an average increase of 0.49%. Consequently, they had no significant influence on the mass and volume variation of the samples. On average, the EGP panels had a swelling (volume increase) of 0.62% with 1% increase in moisture content.
4. The dimensional variation of the pieces did not significantly influence the width and thickness. The door jambs had an average 0.19% (0.41 mm) width increase for 1% increase in moisture content, within the expected range; and the thickness had an average increase of 0.06% (0.14 mm).
5. In general, the best combination to minimize the effects of anisotropy and warping is the use of a 32 or 56 mm coverslip with radial or cross-sectional arrangement. However, it is important to highlight that, whenever possible, one should analyze, in an individualized way, which of the three warpings it is intended to be neutralized.

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