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WOOD PARTICLEBOARDS REINFORCED WITH THERMOPLASTICS TO IMPROVE THICKNESS SWELLING AND MECHANICAL PROPERTIES

LÓPEZ, Y. M., PAES, J. B., RODRÍGUEZ, E. M., GUSTAVE, D., GONÇALVES, F. G. Wood particleboards reinforced with thermoplastics to improve thickness swelling and mechanical properties. **CERNE**, v. 24, n. 4, p. 369-378, 2018.

HIGHLIGHTS

Were evaluated Wood plastic composite with particles of *Pinus caribaea* made by extrusion molding.

The physical and mechanical properties of the boards were improved by increasing the density.

Mixtures of different thermoplastics between the dosages of raw material allows to obtain boards with better mechanical properties.

The study allows to obtain the formulations with better dimensional stability.

ABSTRACT

The manufacture of forest products with high physical and mechanical properties contribute to the development of the forest industry in obtaining more resistant products with potential in the construction sector. In this context, to contribute to the study of reconstituted panels this article discusses the manufacture of panels reinforced with recycled thermoplastics (WPC), which had as raw material sawdust of *Pinus caribaea* and as recycled thermoplastics polyethylene terephthalate, low-density polyethylene and polypropylene. The panels were obtained by extrusion and developed in four treatments with different proportions of raw material. Thickness swelling rates of the manufactured WPC were evaluated by immersing them in water at room temperature and monitoring thickness changes for several weeks. A swelling model developed by Saeed Kazemi Najafi was used to study the thickness swelling process of WPC. The WPC were characterized by thickness swelling, apparent density, static blending, longitudinal compression and tensile strength. The treatment with 50% sawdust and blend of all thermoplastics (T5) showed a tendency to reduce the thickness swelling because it absorbs 0.28% of water and maintains the balance of water absorption in 16.2% the apparent density was 1206 kgm⁻³. For the mechanical properties, the static blending, longitudinal compression and tensile strength are around 24.6, 142.4 and 32.8 MPa, respectively. These characteristics make a treatment the best response. Hence, is suggested this board be used for structural applications, such as interior or exterior walls, since the water absorption index is low and high mechanical properties allow being more resistant.

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INTRODUCTION

Technological advances and market competitiveness make it necessary to seek improvements in the quality of industrialized products for civil construction. In the scenario of modernity and quality of materials, technology has created new products derived from wood, either in different forms or in combination with other materials, in search of environmental benefits, and better product performance (Horta et al., 2017).

In this sense, wood plastic composite (WPC) corresponds to one of these technologies taking into account that it is a modern and ecologically viable product. This product involves two or more raw materials, originating from the wood mix, and recyclable materials such as thermoplastic waste and chemical additives to provide some desired characteristic.

This process results in panels with better qualities and properties that mimic wood and in natural conditions can replace it. Among the components of plastic wood there is also another internationally known as plastic lumber, which is nothing more than that wood plastic composite (WPC) made from recycled plastics, these materials also compete with those of WPC (Keskisaari; Kärki, 2018).

The swelling is one of the most important physical properties of composites. This evaluation is fundamental in the development of the boards industry and is necessary to origin products stronger and with higher quality, which meet the growing needs of the construction sector. This enhances the decision-making process about the use that can be given to each type of board, as there is also a proportional relationship between the physical properties and their the mechanical behavior (Arnantha et al., 2017).

Controlling the physical properties ensures product quality for a particular use, because many conventional panels, such as medium-density fiberboard (MDF), oriented strand board (OSB) and particleboard suffer considerable dimensional deformation, which limits their application in outdoor conditions. However, technical term, for wood plastic composite (WPC) weathering conditions do not cause significant damage, allowing a wide range of applications (Tenorio et al., 2012).

The wood exhibits an affinity for water and is plastic enough to physically expand during adsorption. Reversible swelling occurs when wood adsorbs water and forms a solid solution. The wood can return to its original size eliminating excess moisture. The proportion of total swelling that is reversible on wooden boards is less than that of unprocessed solid wood (Hosseinihashemi; Badritala, 2017).

The swelling is directly related to the hygroscopicity of the wood and its affinity for water. The drying of the panels at high temperature during pressing reduces a bit the hygroscopicity. This drying process reduces the equilibrium moisture content (EMC) by as much as 3% compared to air dried wood. Therefore, wood plastic composites can condition less affinity for water than wood raw material, and exhibit less swelling (Ashori; Nourbakhsh, 2010).

Recycled thermoplastics are used for processing because of their compatibility with the wood particles favor the formation of wood plastic composite, achieving a highly efficient encapsulation of the wood particles by thermoplastic, which ensures low penetration of water into the composite (Yemele et al., 2010).

Hence, the dosages should be adequately studied to ensure an optimized technological process using recycled thermoplastics. This process would provide good quality boards with acceptable physical and mechanical properties (Renner, 2010; Clemons, 2010). Further with the addition of chemical additives such as plasticizers and coupling agent, some of the formulations obtained may have similar or better properties than the same synthetic plastic (Jiang et al., 2015).

Under ambient conditions in a tropical climate, research was done on the effects of swelling of different blends of recycled thermoplastic wood composite, to determine its hygroscopicity. Najafi (2013) cites several studies on this theme. In this context, to contribute with development of forest products to better properties that could be used in the construction sector through various materials.

Nowadays wood wastes and plastic garbage have been a main environmental concern. Wood plastic composites are obtaining great attentions in industrial sectors and academics due to their favorable properties, which include low density, low cost, renewability and recyclability as well as desirable mechanical properties. WPC only used for non-structural purpose such as flooring, decking, fence and any other use (Zhang et al., 2012).

As the use of WPC material extends to include more structural applications, there is an increasing need to determine design values appropriate for designing structural WPC elements. The decision to use a WPC product in place of another, generally speaking, should be predicated on achieving greater performance, reduce price, or reduced environmental impact. There are a number of published studies in WPC research; most of them were held in overseas using its local kind of wood and using compression mold method (Schwarzkopf; Burnard, 2016).

This research was conducted with the objective of evaluating the thickness swelling and mechanical properties of wood plastic composites produced with thermoplastics materials polyethylene terephthalate, low-density polyethylene and polypropylene and sawdust from *Pinus caribaea*. The perspective of using these composites guarantees to increase knowledge about new sources about this panel for the civil construction.

MATERIAL AND METHODS

Materials

For the manufacture of the board was used wood (sawdust) of *Pinus caribaea*, whose density was $450 \text{ kg}\cdot\text{m}^{-3}$. The residues were obtained from sawmills that process these forest species, which were shredded in a Willey mill, having been classified in appropriate sizes (40 - 60 mesh) for moisture content test. For this analysis, 2 g of sawdust of each species were used in duplicate, which were dried in an oven at $103 \pm 2 \text{ }^\circ\text{C}$ until constant mass. This evaluation was conducted according to the Technical Association for the Pulp and Paper Industries - TAPPI T 264 cm-07 (2007). The control panel was made from *Pinus caribaea* wood, cast with a base of urea formaldehyde adhesive and pressed in dimensions similar to the plastic wood board.

Also, were used three types of thermoplastics, such as polyethylene terephthalate (PET), low density polyethylene (LDPE) and polypropylene (PP), these were chosen unlike the others because they are the most used in social consumption and waste are more found.

Wood plastic composite material preparation

Sawdust particle size estimation was determined by homogenization and scaling, using a 100 g sample, which was subjected to a vibrating screen for 30 min. Then larger amounts of sawdust were sieved and preferably used particle size of between 0.3 cm and 0.7 cm, the larger particles were crushed in a hammer mill until reaching sizes of waste particles and taking advantage of most of the material (sawdust). This procedure was used according to studies carried out by Jördens and Alabama (2010).

These thermoplastics were classified, washed and crushed into particles of between 0.5 and 0.8 cm according to the studies carried out by Martinez et al. (2014). With these dimensions and the temperature of the production process (mixed, granulated and extruded) exceeding the values between 120 and 200 $^\circ\text{C}$, it was possible that plastic particles were mixed with

wood, since the melting temperature of thermoplastics used varies between 80 and 150 $^\circ\text{C}$. Under these experimental conditions, we obtained good quality of wood plastic composites.

Manufacturing of the composite

Extruded molding was performed by a single-screwed extruder with 7 mm screw diameter and 28:1 length to diameter ratio. The extruding temperature was between 160 and 170 $^\circ\text{C}$, and the extruding speed was $0.7 - 0.8 \text{ m}\cdot\text{min}^{-1}$. The cross-section dimensions of the extruded samples were $250 \times 6,000 \times 16 \text{ mm}$ (width x length x thickness) for each treatment. Were divided into five parts with dimensions of $1,000 \times 250 \times 16 \text{ mm}$ (length x width x thickness) for each treatment, and then randomly extracted the test samples for analysis. Five replicates were evaluated for each of the evaluated properties (four properties), totaling 100 test samples including the control.

The dosages used allow grouping of all possible variants, which facilitate conducting assessments related to thickness swelling for each of the boards obtained. Five specimens were processed for each board with the dimensions of $50 \pm 1 \text{ mm}$, and a thickness of 16 mm, according to the British Standards Institution - BS EN 317 (1993). These were dried in an oven at a temperature of $103 \pm 2 \text{ }^\circ\text{C}$ for one period of 24 h. The thickness of the specimens was then evaluated with an accuracy of 0.001 mm prior to immersion in water, at ambient temperature range between 25 and 30 $^\circ\text{C}$. The composition of the treatments used for each of the treatments is show in Table I.

TABLE I Proportion of raw material for each treatments.

Treatment	Sawdust (%)	Recycled thermoplastic		
		PET	LDPE	PP
T1 (Control)	100	--	--	--
T2	50	50	--	--
T3	50	--	50	--
T4	50	--	--	50
T5	50	16.6	16.6	16.7

PET: polyethylene terephthalate; LDPE: Low-density polyethylene; PP: polypropylene.

Evaluation of thickness swelling

The thickness swelling was measured with a digital pachymeter, precision of 0.01 mm. Then the test samples were placed in distilled water and kept at room temperature. The thickness of the samples was measured at different times (4, 8, 16, 32, 48, 64, 96, 128, 192, 256, 320, 384, 448, 576, 640, 768, 832, 960, 1216, and 1500 h) during the long-term immersion. This methodology was used according to studies carried out by Najafi (2008),

and modified in this investigation up to a time of 1500 h. The measurements were finished after the samples reach the equilibrium thickness. Equation 1 calculated the values of the thickness swelling in percentage, TS: Thickness swelling at time t; T_0 : initial thickness of test samples; $T(t)$: thickness at time t.

$$TS(t) = \left(\frac{T(t) - T_0}{T_0} \right) \cdot 100 \quad [1]$$

It was considered the model of swelling based on wood compounds, this model allowed to determine the swelling velocity parameter (K_{SR}), and applied to the data that were tested to quantify the swelling cup; the model used is showed in Equation 2, $TS(t)$: thickness swelling at time t; T_0 : initial thickness; T_∞ : equilibrium thickness swelling; K_{SR} : coefficient of initial swelling; t: time of observation.

$$TS(t) = \left(\left(\frac{T_\infty}{T_0 + (T_\infty - T_0)e^{-K_{SR}t}} \right) - 1 \right) \cdot 100 \quad [2]$$

Mechanical testing

The evaluation of the mechanical properties was carried out in accordance with the ASTM D 7031 – 04 (2004) standard. This standard establishes the methods for obtaining, preparing and conditioning the test pieces to be evaluated. Was evaluated the mechanical properties of the composites, tensile strength, static blending and longitudinal compression, as well as considering some physical properties such as density.

Statistical evaluation

The data were statistically evaluated using normality test (Kolmogorov-Smirnov) and homogeneity of variances (Cochran). The statistical difference between each treatment was analyzed using non-parametric test (Kruskal-Wallis, $p < 0.05$) and intervals by the Spearman test.

The process of detecting the influence of each variable was performed by multiple linear regression analysis (MLR) using F test of the partial regression coefficients associated with each independent variable, and then the Stepwise method (SWM), which rejects the independent variables used that do not affect the dependent variable, but also consider the interactive effects of the independent variables.

RESULTS AND DISCUSSION

Considerations on raw material

The analysis made to evaluate the moisture content of the wood (sawdust) allowed determining that raw

material had to go through a drying process and reduce its moisture content of 15% to an adequate humidity for the WPC productive process of 4%. These conditions allow optimizing the technological process of the board and improving the interface between plastic and wood particles.

According to studies carried out by Solar and Melcer (1978) it can be considered that the compatibility of sawdust and thermoplastics is given in that this synthesis process of the board is carried out at high temperatures, changes in the components of the cell wall of wood can occur, as it is the degradation of the hemicellulosic components of the wood, due to the low resistance of the hexosanes, changes in the polymerization of cellulose - hemicellulose and a decrease in the crystallinity of the hemicelluloses can occur.

In addition, structural changes may occur with rupture of the polysaccharide complexes - polysaccharides and lignin - polysaccharide. All these changes caused by the high temperatures, facilitate the formation of bonds of the wood particles with the plastic, favoring with it the synthesis of the board and thus obtain a good quality in the formation of the wood plastic composites.

Thickness swelling of panels

The Figure 1 shows the density and water absorption of the thermoplastic for PET, LDPE and PP. According to Moya et al. (2012) the observed differences are mainly caused by the higher molecular weights and the higher structural packing degrees of the styrene-butadiene monomers; they were processed by injection molding, with the lowest molecular masses of the polymers PET, LDPE and PP and are distributed in the form of linear structures, with a variable amount of side chains present.

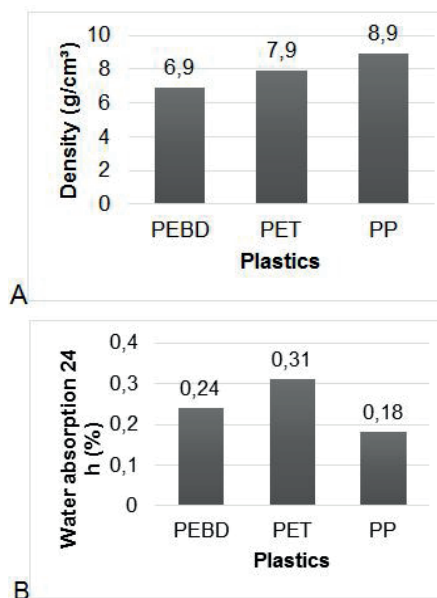


FIGURE 1 Physical properties of used thermoplastics. A) Density; B) Water absorption during 24 hrs.

However, after 24 h, these thermoplastics show a very low water absorption capacity that does not significantly affect the swelling, these conditions when they are passed to the plastic wood board influence the resistance to water absorption, and low percent of swelling of the board

In figure 2 shows the predicted curves of thickness swelling of treatments analyzed (WPC), it was not considered the control panel for better visualization of the wood plastic composite (object of study). The results shown are related to swelling model obtained in the research, it is well adjusted to the experimental data for most treatments being more efficient for treatment 5, where the values of R^2 for the adjustment of the model were greater than 97% (Equation 3).

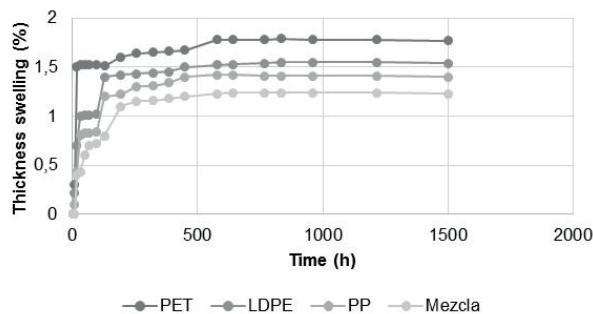


FIGURE 2 Effect of thermoplastic content in wood plastic composite in thickness swelling during water immersion.

This model provides a better prediction for the initial portion of thickness swelling of treatment that contains the mixed thermoplastics. This phenomenon can be related to a greater internal disunion between wood particles and plastics or damages that could have occurred at higher rates of swelling (greater water consumption) that could eventually lead to changes and the tendency to favor the swelling process of thickness, these conditions could induce some error in the model of swelling prediction

According to Yeh et al. (2009) thickness swelling generally increases with immersion time in water, mainly for agglomerated boards such as the control board used in this research. However, the swelling in the wood plastic composites is given by the effects that cause the fusion of the thermoplastics on the wood particles, which encapsulate the same inhibiting their hygroscopic capacity.

This provides greater resistance to the absorption of water and improve its dimensional stability. The type of thermoplastic used can influence the swelling of the compounds; the obtained results show that by means of the mixture of the thermoplastics used represented by the treatment 5 the values obtained were lower in relation to the other treatments.

Mixing thermoplastics with wood to produce wood plastic composite offers the best properties of resistance to swelling by water immersion (Table 2). The treatment 5 showed the best result in terms of the swelling equilibrium, with a value of 1.463 and 16.2% of water absorption. The individual polypropylene (PP) used, in relation to the others, was the showed significant values; this was because of its density and chemical composition.

TABLE 2 Swelling thickness parameter values for wood plastic composites during immersion in water.

Treatment	Waba (%)	T0 (mm)	T ∞ (%)	TSt (%)	KSR ($\times 10^{-3} \cdot h^{-1}$)	R ²
TI (Control)	70.5	5.215	6.28	24.6	0.25	0.96
T2	18.8	1.579	1.79	9.0	0.82	0.97
T3	18.2	1.468	1.55	9.7	2.41	0.98
T4	17.4	1.448	1.42	7.8	4.00	0.98
T5	16.2	1.399	1.24	4.6	4.80	0.99

W_{aba}: equilibrium water absorption; T0: initial thickness; T ∞ : equilibrium thickness; TSt(∞): equilibrium thickness swelling; KSR: swelling rate parameter; R²: correlation coefficient.

For the panel control one of the disadvantages, when compared to the plastic wood, it is the non-return rate in thickness. This is because the total thickness swelling of these compounds is given by the sum of two main factors, one related to the hygroscopic nature of the wood, and the other related to the release of compression stresses (Gonçaves et al., 2014). This process is usually accompanied by the loss of resistance of the panel, which can be demonstrated when comparing the mechanical properties between the panels tested in this study.

Statistical values show the differences between each of the models obtained. The coefficient of determination values were of $R^2 = 0.996$ and 0.998 respectively. Analyzing the statistical significance of $p < 0.05$ of the regression coefficients of the selected model, implies that the independent variable explain the behavior of the dependent variable, in addition to meeting the perceived multicollinearity, with acceptable values of tolerance and variance factor. The values of thickness swelling of manufactured composites can be obtained by substituting the coefficients of the regression in the model showed by Equation 3, with $R^2 = 0.972$, K_{SR}: swelling rate parameter.

From the model obtained on the K_{SR} parameter for formula four with respect to the boards obtained from PET, LDPE and PP. A good linear relationship was established between K_{SR} and the plastic type used. Generally, the selected model provides satisfactory predictions from the statistics obtained, when evaluating the thickness swelling for wood plastic composite, using *Pinus caribaea* sawdust and waste thermoplastics of PET, LDPE, and PP.

In treatment 5 the lowest water absorption values were obtained, the thickness swelling parameters

T5 Composite $K_{SR} = 16.652 - 5.311(640h) - 3.179(448h)$ [3]

also gave good response, the effect of the mixture of the different plastics used in this treatment allowed to decrease the K_{SR} parameters to their lower value, thus as the best fit for the model obtained. These results demonstrate a great perspective of using recycled plastics in the elaboration of this type of board.

The swelling values obtained for each of the formulations range from 0.15 to 0.31%. San et al. (2008) showing values of 2.65% from polypropylene (PP) over 60% of sawdust broadleaved trees and 1% chemical additives by injection molding, reported similar results. Adhikary et al. (2008) reported values of 0.7% from PET, with more than 30% *Pinus radiata* sawdust, without additives by compression molding; in turn, they obtained values of 1.60% for compounds made by LDPE, plus 50% of sawdust from the same species.

Using injection molding, Wang et al. (2010) and Moya et al. (2012) obtained values for compounds made 0.20% with PET plus 40% *Pinus radiata* sawdust, without chemical additives and in turn reported values of 0.29% for compounds made from LDPE, plus 60% sawdust for the same species, without additives.

Irrespective of the method used to mold, as the proportions of the thermoplastic increase, the properties are improved. The favorable properties exhibited for wood plastic composite relative to these physical properties, may further be associated with the addition of chemical additives.

They may also influence the interactions of the compound with water, because they allow a greater dispersion of sawdust or wood fibers in the thermoplastic matrix, promoting a better performance of the physical properties; this is attributable to the ability to withstand the moisture matrix with the surface of the wood particles, generating more homogeneous and better physical properties of compounds (Beg; Pickering, 2008; Bouafif, et al., 2009; Haque, et al., 2009; Yadama et al., 2009).

In addition, whilst a favorable performance of the wood plastic composite is attributable to the higher density and swelling of composites derived from wood (Moya et al., 2012), does not have high density, to perform the immersion in water. However, the water has little possibility of penetrating into the board.

The matrix or continuous phase of the compound significantly affects its physical and mechanical properties, because it receives and transmits the energy applied to the fibers vegetable when the compound is subjected to certain mechanical conditions (Renner, 2010). Two

types of polymer matrices are used for making these compounds: thermoplastic and thermosetting matrices.

Thermoplastic matrices are the most used; the most common matrices are polypropylene (PP), polyethylene terephthalate (PET) and low-density polyethylene (LDPE), and to a lesser extent, polyvinyl chloride (PVC) and acrylonitrile butadiene styrene (ABS). While the thermosetting matrices, such as phenolic and epoxy, are used in smaller quantities, they are mainly for products with higher mechanical strength (Zhang et al., 2012).

To the thermoplastic matrices, PET, LDPE, and PP are used more than PVC and acrylonitrile butadiene styrene (ABS) that require lower processing temperatures, which fluctuate between 170 - 205 °C. These temperatures are suitable for working with fibers, as their cell walls are able to withstand temperatures prior to thermal denaturation. However, other thermoplastic like this PVC and ABS require higher temperatures, respectively 270 to 230 °C for processing, and compounds made from these thermoplastics require special manufacturing methods that reduce the exposure time of the fibers at high temperatures (Rafighi et al., 2014).

In addition, thermoplastics can be recycled to be used as matrices for new compounds, either fibers or flour mixtures, or with virgin thermoplastic materials generating similar properties as virgin thermoplastic. Generally, the PET, LDPE, and PP, and the ABS and PVC thermoplastics demonstrate certain similarities and differences in various physical properties between more explanation these Figure I (A and B) the average density, water absorption, tensile strength and penetration data were obtained from tests conducted according to literature (Bouafif et al., 2009).

Studies concerning the effects of water on wood plastic composites by means of spectroscopy during a certain time. The dielectric properties of the boards were found at frequencies between 0.2 and 1.0 Terahertz (THz) to vary the water content. In this research, a model was developed to estimate the dielectric behavior based on the water content and verified experimentally. The methodology used for the analyzed materials polyamide (PA) and wood plastic composite (WPC), included the calculation of the index of refraction and the coefficient of absorption of the water bound between the polymers used and correlated the results with the gravimetric measurements (Jördens et al., 2010).

Given the sensitivity of terahertz radiation to water, it suggests that this technique can also be used to analyze the behavior of these types of boards against the effects of water by means of non-destructive methods and without contact of the water content. The results obtained in this

study were similar, obtaining very low swelling values in relation to the balance of water absorption of the boards.

On the other hand, Wang et al. (2010) poses of the absorption of water is one of the key parameters in the evaluation of the quality of wood and plastic compounds. Analyzed the influence of the surface treatment of lignocellulosic particles on the absorption of water from composite materials from PVC and bamboo (*Phyllostachys pubescens*) particles. The relationship with water absorption, porosity, thermal property, and hemicelluloses content was evaluated.

In general, the surface treatment improved the water resistance of PVC compounds reinforced with bamboo particles. Compared with the results obtained in this study, the wood particles of *Pinus caribaea* used in the manufacture of the board were encapsulated by the different thermoplastics tested, which provided a good behavior before the effects of water, mainly in the treatment that were mixed all the thermoplastics.

Physical-mechanical proprieties

In Table 3, it can be seen that among the boards produced with thermoplastics separately not statistical differences were detected, except for the control and treatment 5 that was elaborated by mixing all the thermoplastics. However, of the others treatment 4 presented better results, in spite of not having statistical differences between treatments 2 and 3, it can be estimated that their characteristics are good.

The results achieved by treatment 4 may be related to the use of PP (polypropylene) as a thermoplastic. This type of plastic stands out among the other plastics used in this research due to its lower water absorption and higher density. These properties were transferred to the board providing better characteristics. Among them, the increase in density is a parameter directly proportional to the mechanical properties of the boards evaluated, with the highest average values for treatments 4 and 5.

Lower results were presented by Nourbakhsh (2010) for particle boards, as well as Yan et al. (2012) in the manufacture of fiber boards by alkaline treatment to wood, The results obtained in the mechanical properties of

the compounds in relation to tensile and flexural strength show values between 21.9% and 16.1% respectively, these results are still they are inferior to those obtained in this investigation, which represents the treatment 5.

On the other hand, Maciel et al. (2004) in wood plastic composite made from *Pinus elliottii* wood and PET and polystyrene (PS) thermoplastic, obtained results between 10 and 15 Mpa for the rupture modulus (MOR) and between 2 and 3 Gpa for MOE, similar to those found in this investigation. These results show that wood plastic composite can achieve better applicability from their physical-mechanical properties. These allow them better adaptability and durability in conditions where conventional boards tend to deform dimensionally.

The thermoplastics used in this research (PET, LDPE and PP) showed a great potential to improve the mechanical properties of wood plastic composite, in this way they contribute to achieve the wood components used are compressed or break the links between wood and plastic particles, because these boards have significantly higher specific resistances, which given its durability and ease of maintenance this material is an alternative to wood in such mechanical situations.

Bajracharya et al. (2014) in study on mixed plastic compounds reinforced with fiberglass obtained good results in the mechanical properties, as well as Dias and Alvarez (2017) evaluated some mechanical properties in wood and wood plastic boards, the same relating on which the compounds of wood plastic have high values of resistance to compression, as well as specific resistance to traction, which shows that this type of board compared to wood have a great potential for use in conditions where they can be compressed by the action of compression forces or parallel traction

In this sense, studies conducted by Bajracharya et al. (2017) presented results on the durability of these compounds. They show that exposure to a temperature of 60 °C or higher weaken the adhesion of the glass fiber due to the softening of the mixed thermoplastics, resulting in debilitated mechanical properties. Such effect does not occur in the wood plastic composite obtained in this study, because the wood particles do not allow

TABLE 3 Physical-mechanical properties of wood plastic composite.

Type of plastic	Treatment	Density (kg·m ⁻³)	Static bending (Mpa)	Longitudinal compression (Mpa)	Tensile strength (Mpa)
Control	1	470 (1.31) a	3.8 (2.25) a	88.6 (3.42) a	14.8 (1.66) a
PET	2	1002 (1.28) b	13.8 (2.18) b	108.6 (3.24) b	20.8 (1.46) b
LDPE	3	1018 (1.24) b	15.9 (2.21) b	110.1 (3.22) b	21.2 (1.48) b
PP	3	1022 (1.21) b	16.2 (1.64) b	110.2 (2.48) b	22.4 (1.28) b
Mixture	5	1206 (1.16) c	24.6 (1.48) c	142.4 (2.24) c	32.8 (1.21) c

Numbers in parentheses are standard deviation. Means followed by the same letter in the column do not differ (Tukey $p > 0.05$).

high temperatures to be transferred to the board for a short time.

Another result achieved by these researchers reflects that the exposure to ultra violet (UV) radiation results in the contraction of the samples improving the interfacial bond given to the addition of glass fibers, while in wood plastic composite can also be improved the connections between the plastic and wood particles. On the other hand, exposure to humidity results in swelling of the samples that weakens the interfacial junction. In this sense, boards made with 100% plastics (plastic lumber) have advantage over wood plastic composite, due to the low humidity input resulting in higher matrix properties.

CONCLUSIONS

The changes in the thickness swelling properties extruded plastic boards and manufactured in similar conditions were monitored during 1500 h to investigate the effect of thermoplastics against the action of water. Although certain parameters such as equilibrium in the water absorption and initial swelling of the compounds were different in each treatment much more serious than for the control board. This difference can be given to the efficiency in the encapsulation of wood particles by the thermoplastic matrix, taking into account that the free wood particles favor the absorption of water and the presence of fault zones, such effects were improved from the treatment 5 by mixing different thermoplastics in the composition of the board.

The results suggest the use of different thermoplastics mixed with wood particles in equal concentrations. Composite containing PET, LDPE and PP (treatment 5) have lower equilibrium thickness swelling 1.24%, and shorter equilibrium time to reach equilibrium thickness swelling (4.6%). The swelling model provided a good predictor of the hygroscopic swelling process of wood plastic composites immersed in water to 97%. Treatment 5 have higher swelling rate parameter ($K_{SR} = 4.80$) than others treatments. It is important to note that in the swelling model, K_{SR} was obtained considering the whole thickness process until it was equilibrated; i.e., it is dependent not only on the initial rate of swelling but also on the equilibrium thickness swelling of the composites. This means that for composites where mixed thermoplastics were used with a lower thickness of equilibrium swelling, it will take less time to reach the equilibrium thickness, so that the K_{SR} parameter will reach greater magnitude.

The dosages of raw material used in treatment 5 allowed obtaining good results in terms of mechanical

properties, for static blending, it obtained 24.6 MPa, 142.4 MPa for longitudinal compression and 32.8 MPa for tensile strength. These results can be given by the proportional relationship that exists between the density and the mechanical properties, this treatment reached a density of 1206 kg.m⁻³, this physical property in the plastic wood boards infer a good compaction and interphase between the particles of wood and plastic, which provides fewer fault zones on the boards which can weaken their mechanical resistance. Taking into account these results, good quality boards can be obtained from forest residues and recycled thermoplastics, so the use of this type of board with efficiency for civil construction is recommended both indoors and outdoors.

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