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Internal Bond of Particleboards Made of Three Wood Species Mixture with Empty Fruit Bunch of *Elaeis guineensis*, Leaves of *Ananas comosus* or Tetra Pak

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Some countries with tropical climate produce a great variety of lignocellulosic waste from crops planted in small areas and their urban areas produce a great amount of waste Tetra Pak packages. A possible solution is to incorporate this waste in particleboards. The main objective of this work is to determine the relation in a mixture of particles of empty fruit bunch of *Elaeis guineensis* (EFB), pineapple (*Ananas comosus*) leaves (PL), and Tetra Pak packages (TP) with 3 kinds of wood from forest plantations (*Gmelina arborea*, *Tectona grandis* and *Cupressus lusitanica*). The proportions 50:50, 70:30, and 90:10 (residue:wood) with adhesive at 6, 8, and 10% (weight/weight) were tested for density and resistance regarding internal bond strength. And these values were compared with particle board fabricated with 100% of wood. The results showed that when the EFB and PL proportion decreases, the IB values increased the 90:10 mixture with 10% adhesive being the one with the highest internal bond. But for matrixes with TP, the highest IB value comes with a 50:50 proportion with 10% adhesive.

Keywords: Tropical species, strength, lignocellolose residues, agricultural crop.

Cohesión Interna De Tableros Fabricados De Mezclas De 3 Maderas Y Fruto De Palma (*Elaeis guineensis)*, Hojas De Piña (*Ananas comosus*) Otetra Pack

RESUMEN

Algunos países con clima tropical producen una gran variedad desechos lignocelulósicos de cultivos plantados en pequeñas áreas y además los centros urbanos producen una cantidad de residuos tipo tetra pak package. Una posible solución a estos desechos es incorporarlos a la producción de tableros de partículas. El objetivo principal de este trabajo determinar la relación en una mezcla de partículas de frutos vacíos de *Elaeis guineensis* (*BPF*), hojas de *Ananascumosos* (*LP*) y paquetes tetra (*TP*) con 3 maderas de plantaciones forestales (*Gmelina arborea*, *Tectona grandis* y*Cupressus lusitanica*), comúnmente utilizadas en la fabricación de este tipo de tableros. Las proporciones de 50:50, 70:30

y 90:10 (residuo:madera) con adhesivo en 6, 8 y 10% (peso/peso) fueron probados en su densidad y su resistencia a la cohesión interna(*IB*). Los resultados mostraron que cuando la proporción de EFB y PL decrece, la resistencia a IB incrementa, la mezcla 90:10 con 10% de adhesivo produce los valores de resistencia a la cohesión más alto. Pero a mezcla que contienen TP se tiene los valores más altos en IB en la proporción 50:50.

Palabras claves: especies tropicales, resistencia, residuos lignocelulósicos, agricultura.

Ideas destacadas

Fue fabricado tableros de partículas con una mezcla de partículas de residuos del fruto de la palma aceitera, hojas de piña, madera y tetra pack.
Proporciones de 50:50, 70:30, y 90:10 (residuos:madera) con adhesivos al 6, 8 y 10% fueron probadas en su densidad y resistencia en cohesión interna.
Un decrecimiento de la proporción fruto de palma aceitera y hoja de piña, incrementa la resistencia en cohesión interna.
Tableros de partículas fabricados con tetra pack produces los valores más altos de resistencia en cohesión interna.

Highlights

It was fabricated particleboards with mixture agricultural, wood and tetra pack waste.
Proportions of 50:50, 70:30 and 90:10 with adhesive at 6, 8, and 10% were tested.
A decreasing of empty fruit bunch and pineapple leaf, increasing the internal bond.
Particleboards fabricated with tetra pack produces the highest internal bond strength.

INTRODUCTION

Many small countries in the tropical area have enviable climates, to make it possible to grow a great variety of crops (Bertsch, 2005). Besides, Tetra Pak package (TP) is a beverage and liquid food system widely used in over all the word as an aseptic packaging material. Agricultural crops and packages for drink or food in the country suffer various problems: (i) The crops in general belong to many producers and are distributed throughout all country (Ulloa, 2004). (ii) Post-harvest residues are not being used currently, thus their disposal becomes a problem (Ulloa, 2004). (iii) Some crops have been blamed for environmental problems (Kissinger, and Rees, 2010).(vi) And the amount of waste generated by TP poses a problem, as it increases solid municipal wastes in all the regions of the country.

The solution to the four problems described should be oriented to joining the residues resulting from the harvesting processes (for example pineapple plant) and the processes at the collection center (for example oil palm), in one type of industry or one type of product (Ulloa, 2004). A possibility of combining the residues coming from sawmills, pineapple production, oil palm fruit processing and TP waste can be joint in particleboards. However, although these crops are lignocellulose materials, their Chemical composition is different, which reduces compatibility.

Particleboards were traditionally produced from wood. In the last 20 years, however, a variety of raw lignocellulose materials have been introduced with this purpose (James, 2010). They made from pure agricultural residues or from the combination of wood with other materials present excellent physical and chemical qualities (Hashim et al., 2010). However, the best proportions of these materials are scarcely focused.

The objective of the present study is to determine the best proportions of three different lignocellulose material, 50:50, 70:30 and 90:10 (wood: lignocellulose material), of the empty bunch fruit of *Elaeis guineensis*, pineapple leaves (*Ananascumosos*), TP obtained from the recycling of postconsumer aseptic packaging with three main timber species used for commercial reforestation in Costa Rica (*Gmelina arborea*, *Tectona grandis* and *Cupressus lusitanica*) in particleboards using three different adhesive proportion (6, 8 and 10%). These proportions were evaluated in relation with particle fabricated with 100% of timber species.

MATERIAL AND METHODS

Materials and origin: pineapple leaves from cropped plantation, fibers from the fruit of oil palm, Tetra Pak

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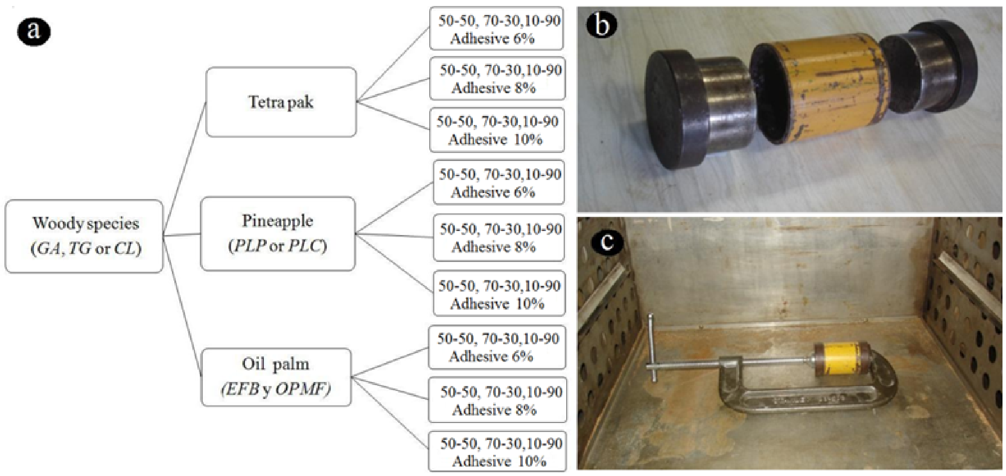

Figure 1. Different mixture of woody species with three different lignocelluloses residues (a), metal rack utilized (b) and press application during heating in the particleboards fabrication.

package (TP) and three different woody species were investigated. The three different species utilized as raw material in the particleboards fabrication were *Gmelina arborea* (GA), *Tectona grandis* (TG) and *Cupressus lusitanica* (CL). They were collected from mature plantations. Plantation ages were 9 yr-old in GA, 16 yr-old in TG and 22 yr-old in CL. Pineapple leaves were obtained from a plantation and its age was 20 months and they were tested in two parts: leaves from the plant (PLP) and leaves from the crown (PLC). Fruit of oil palm were collected in oil palm processing. It was tested two part too: empty fruit bunch (EFB) and oil palm mesocarp fiber of fruit (OPMF), which is a residue produced after oil extraction from fruit. TP were obtained from the recycling of postconsumer aseptic packaging located in ours university.

Materials preparation: Once the materials were collected, the next step was drying them.PL and oil palm fruit were used in a previous research accurately detailed in Tenorio and Moya (2012).In the case of TP boxes, they were washed to eliminate residues of their content; they were dried and cut in 1cm width sheets with the help of a paper cutter. Wood particles were dried using the drying system detailed in Moya, Camacho, Soto-Fallas, Mata-Segreda, & Vega-Baudrit(2013) and they were dried to 6% in moisture content.

Matrixes and Formulations: Each type of wood was mixed with each type of lignocellulosic residue separately (matrixes).Wood with wood or residues with residue combinations were not used. Pineapple leaves from crown (PLC) were not mixed with pineapple leaves from plant, nor were EFB and OPMF mixed either, which means that for each species there were 5 different matrixes: (i) wood-TP, (ii) wood-PLP, (iii) wood-PLC, (iv) wood-EFB and (v) wood-OPMF (Figure 1a). In each type of matrix, 3 different mixture proportions were tested: 50-50, 70-30, and 90-10 (wood weight-lignocellulosic residue).As for adhesive, urea formaldehyde was used in three different percentages (AP = Adhesive Proportion): 6, 8,10% (weight/weight). Figure 1a shows mixtures and combinations of adhesive percentages. The amount of sample per mixture was 135 specimens. For each type of mixture, 5 specimens were prepared; that means a total of 675 specimens (3 species x 5 residues x 3 proportions x 3 adhesives percentages x 5 specimens).Also, in order to compare these results, a formulation was designed with 100% of the wood species using 8% adhesive, which constitutes the type of particleboard commonly used.

Board composition: The specimens were manufactured with three layers: 2 external layers of approximately 2mm in thickness using the finest material (particle size 0.7 to 1.5mm long) and the inner layer, 10mm thick using particles between 1.5 and 6.0 mm.

Specimen preparation: A small metal mold was built to make the specimens for the internal cohesion tests (Figure 1b).This mold consisted of a 5cm-diameter metal pipe, 7.0 cm long with a plug at each end introduced at a 2.9 cm depth as blocks, leaving a 12mm gap in the middle that corresponds to the thickness of the test specimen. The pipes were carefully filled with the amount of glued particle mixture, which allowed for a board density of approximately 1gcm^{-3}; first a layer of fine material, then a layer of thick material, and finally another layer of fine material. The samples were pressed until they filled up the 12mm gap in the middle with the help of a manual press. Then, the specimens were introduced in an oven (Figure 1c) for 8 minutes at 175 ºC. Lastly, the samples were left for a 24 hour room-temperature-conditioning period.

***Density determination and Internal bond test*:** thickness of each specimen manufactured was determined, after the 24 hour period. An axis system

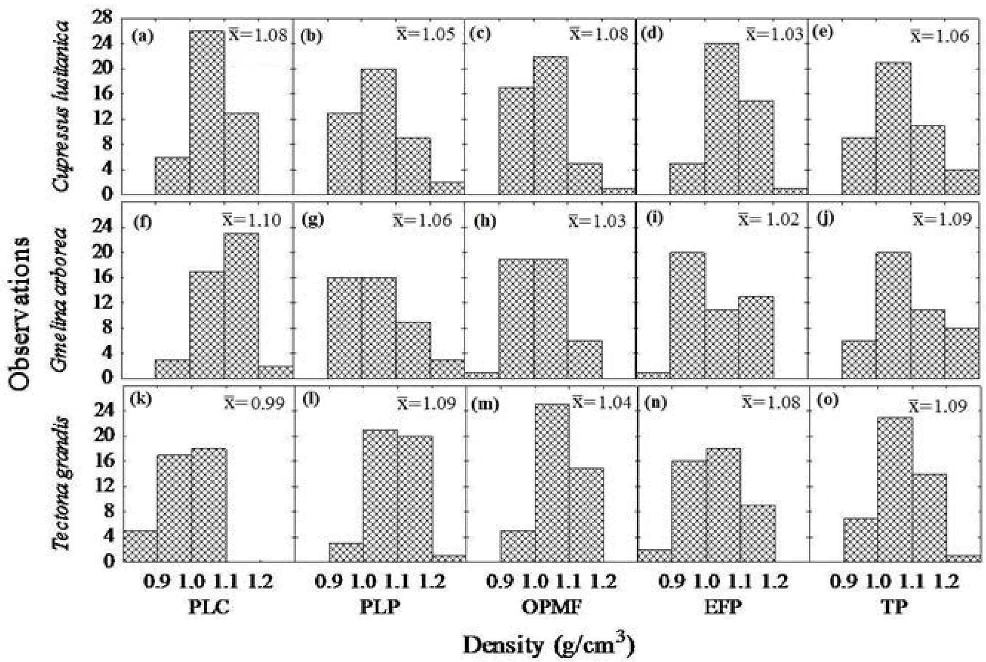

Figure 2. Distribution of the density of particleboards made of *Cupressus lusitanica, Gmelina arborea* and *Tectona grandis* mixture with pineapple leaves, fiber from oil palm fruit and Tetra Pak package.

(cross) was designed in the circular specimen and thickness was measured at each end. Then, the samples were weighted to determine their density with the following equation 1. For Internal bond test: the circular specimens were glued to two pieces of wood and tested in a Tinus Olsen universal testing machine according to the ASTM D-1037 standard (ASTM, 2012).

$$\text{Density}(\frac{g}{cm^3}) = \frac{\text{Weigth(g)}}{\pi * \text{radius}^2 * \text{thickness of specimen}(\text{cm}^3)} \quad (1)$$

***Data analysis*:** a two-way analysis of variance (ANOVA) was applied (proportion of mixture and proportion of adhesive as study factors) for each one of the species and it was applied to the density. The mixture proportion factor (wood: residue) was established in 3 levels: 50:50, 70:30, and 90:10 and the adhesive proportion factor also in three levels: 6, 8, and 10%.Subsequently, for the difference in the averages of combinations, the Tukey's multiple range test was applied at a significance level of $P<0.05$ and $P<0.01$. SAS 8.1 for Windows and STATISTICA 7.0 programs were used for these analyses. Finally, the IB values of each mixture were compared with the IB values for the particleboards fabricated with 100% wood (100% wood: 0% residue) and the IB percent differential (IBPD) was generated with Equation 2 for this purpose.

$$\text{IBDP}(\%) = \frac{\text{IB}_{\text{wood}} - \text{IB}_{\text{Mix}}}{\text{IB}_{\text{wood}}} * 100 \quad (2)$$

Where: IBDP: Internal Bond Percent Differential, IB_{wood}: IB of 100% wood, particleboards with 0% residues, IB_{Mix}: IB of particleboards with wood: adhesive matrix.

RESULTS AND DISCUSSION

Density behavior of the different mixtures used to manufacture particleboards

The average densities from the particleboards of the different matrixes (wood/ pineapple leaf, oil palm, or Tetra Pak boxes) with all 3 adhesive proportions (AP) proved to be very homogenous; a variation of 0.99 to 1.10 gcm^{-3}.The distributions of densities were binomial (Figure 2).The analysis of variance showed that there is no significant difference between the different matrixes. Density homogeneity of the different particleboard matrixes are normal in the manufacture of this type of product (Figure 2), since during manufacture, even if an amount of material and a specific pressure is programmed, the variation happens (Halvarsson, Edlund,&Norgren,2010). The repercussions of the density variations have a direct bearing on the IB of the different combinations. Han, Zhang, Zhang, Umemura, & Kawaim (1998) and Halvarsson, Edlund, & Norgren (2009) found that the density variation within the particleboard samples made out of wheat straw (*Triticumaestivium*) and *Phragnitescommunis* produce IB significant changes and both authors determined that by

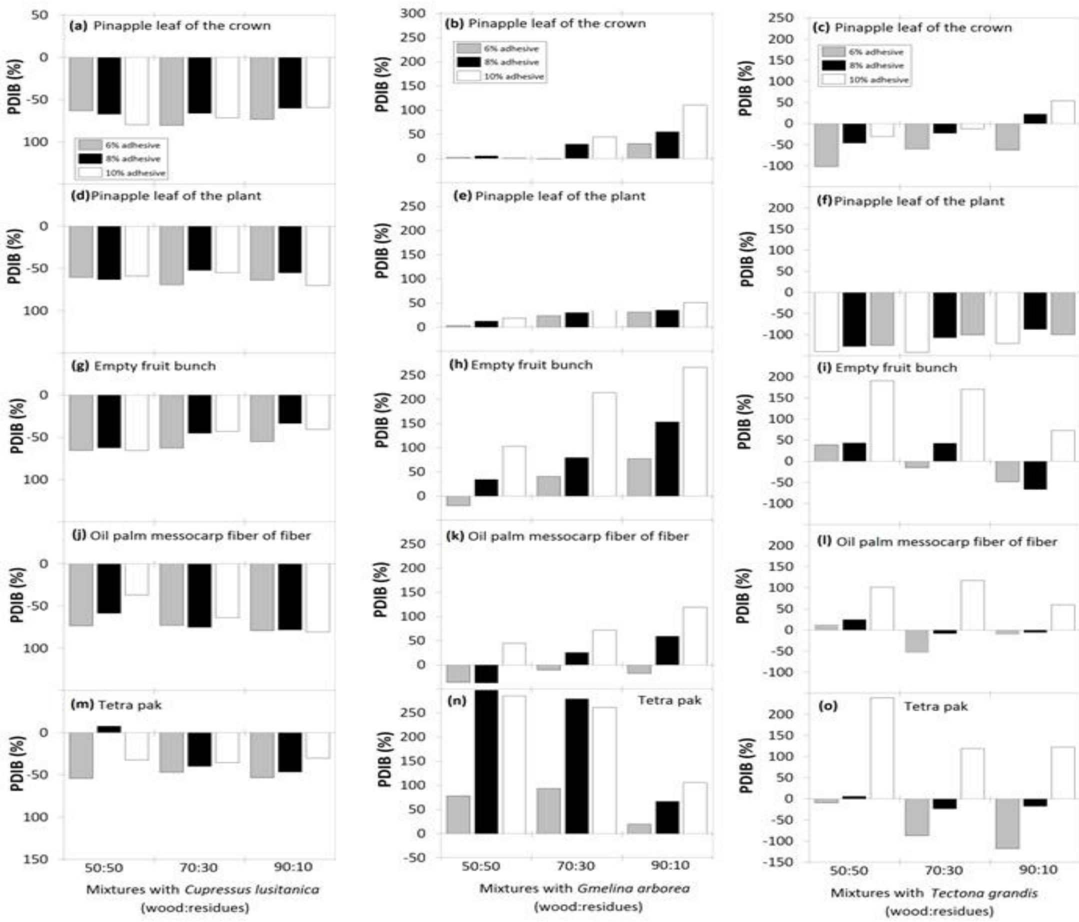

Figure 3. IB value difference (IBPD) between particleboards fabricated 100% of wood and particleboards fabricated with particle of *Cupressus lusitanica*, *Gmelina arborea* and *Tectona grandis* mixture with pineapple leaves, fiber from oil palm fruit and Tetra Pak package.

increasing density, there is an IB increase also. Furthermore, said authors mentioned the importance of having uniform density values to get a property-uniform product.

IB difference between mixture particleboards and 100%-wood particleboards

The evaluation of the IB value difference (IBPD) and between the control/pilot particleboards (100% wood chips: 0% lignocellulosic waste) in the different species and adhesive proportions is shown in Figure 3.In the case of particle boards manufactured with PLC (Figures 3a, 3b &3c) behavior was different between the three species. In CL, IBPD was negative, in other words, no IB value exceeded the IB value of particleboards manufactured with 100% CL (Figure 3a), but GA and TG woods presented positive IBPD (Figure 3b & 3c).In both species, the IBPD for the AP 90:10 mixture with 6, 8, and 10% adhesive was higher than the particleboard made out of 100% of those woods. In PLP mixtures, a great IBPD variation was also found (Figures 3d, 3e & 3f) where CL and TG particleboards (Figs 3d & 3f) presented positive values and only GA showed positive differentials. The 90:10 mixture at 10% adhesive presented the highest IBPD value in relation to particleboards manufactured with 100% of those timbers (Figure 3e).

For particleboards with oil palm components, IBPD of the EFB mixture in the three timber species showed very different behaviors. The CL-EFB and CL-OPMF matrixes presented negative IBPD (Figures 3g and 3j), in other words, none of the mixtures exceeded the IB for the 100% CL wood chipboard. In matrixes GA-EFB, GA-OPMF, TG-EFB and TG-OPMF, IBPD were positive (Figures3h and 3k).In the case of TG-EFB and TG-OPMF (Figures 3i and 3l) there were different behaviors between the mixtures with the different adhesive dosages, the 10% proportion being the one with the positive IBPD in all mixtures with the 3 timber species.

In particleboards with TP mixtures, IBPD showed a very different behavior in comparison with the pineapple and oil palm blends. For CL mixtures, IBPD values were negative with the exception of the 50:50 mixture at 8% AP (Figures 3m, 3n and 3o).For GA mixtures, the different particleboards presented a positive IBPD (Figure 3m).The TG-TP-10 matrix in the 50:50 mixture showed the highest IBPD value.

Particleboards involving pineapple show the lowest decreasing of resistance of values (Figure3) followed by those manufactured with oil palm (Figure3).These variations are attributed to the differences in composition of the different lignocellulosic components. In the case of the empty fruit bunch and oil palm fruit, it has been found that they contains close to 50% cellulose, 19% lignin, and pH 6 (Sreek-Ala, Kumaran, & Thomas, 1997; Moya, Camacho, Soto-Fallas, Mata-Segreda, & Vega-Baudrit, 2015); unlike pineapple, which presents a pH 4 or 5 with a lower amount of cellulose and lignin (Moya et al., 2015; Nomanbhay and Palanisamy, 2005).In the case of TP, the amount of cellulose exceeds 65%, there is little lignin and pH is 7 (neutral).These differences, specially a pH close to neutral (like with TP and oil palm) allow for a better interaction between the mixture wood: residue. In contrast, pineapple residues showing lower pH values have shown a poor response to UF adhesive, because active cellulose hydroxyl groups are scarce and their reaction capacity is reduced with UF (Han, Zhang, Zhang, Umemura, & Kawaim, 1998).

In pineapple and oil palm residues, the mixture with the lowest PDIB values was the 90:10 in comparison with other mixtures. Also, the differences found in particleboards manufactured with one timber combination: pineapple waste or oil palm can be explained by the compatibility and proportions of the wood: waste matrix within the particleboard (Grigoriou, 2000; Sauter, 1995). For instance, Sauter (1995) and Grigoriou (2000) showed in the manufacturing of pine and hay particleboards, internal bond tends to increase when the wheat proportion decreased in the board. The explanation for this decrease was attributed to the presence of silica and wax, which weaken the compatibility of wood and low pH of wheat hay that directly affect the UF adhesive curing process. Therefore, according to this study, the increase of IB when reducing the pineapple and oil palm components can be attributed to the small compatibility of wood with the residue and the effect of their pH during the UF adhesive curing process.

Another relevant aspect is the difference found in the PDIB of TP variation (Figure 3). The PDIB values were the lowest values. These differences can be explained by the limited influence of extractives and factors such as pH for pineapple and oil palm waste on the UF curing and this high AP allows for a higher activity of hydroxyl groups of wood and UF component (Sauter, 1995).

Particleboards manufactured with TP showed a different behavior than pineapple or oil palm. The increase in the TP proportion on the board matrix decreases PDIB (Figure3).This behavior can be explained by the fact that TP shows high cellulose content, a low extractive content and a neutral pH (Moya et al., 2015) An higher cellulose proportion increases resistance of the chipboard as the cellulose improves the UF adhesive curing process (Trianoski, Iwakiri, & De Matos., 2011).Xing, Zhang, & Deng. (2004) taking particle board manufacturing with UF as reference, it was found that better resistance comes when pH for matrix particleboards is close to 7.Therefore, particleboards manufacture with high TP percentages increase the possibility of cellulose and the small presence of extractives and their neutral pH increase adhesive compatibility (Korkmaz, Yanik, Brebu, & Vasile, 2009).

CONCLUSIONS

There were no significant differences in the density of each of the matrixes used, which varied from 0.99 to 1.10 gcm^{-3} and presented a binomial distribution. The IB values in relation to particleboards fabricated with 100% wood of the different matrixes in particle boards were different. Among the matrixes with pineapple waste (PLC and PLP) and CL, the ones with the best performances were CL-PLC-8 and CL-PLC-10 in 90:10 and 70:30, while in GA-PLC, the 90:10 and 70:30 combinations with 6, 8 and 10% were the ones with the best resistance. While the 90:10 combination at 10% showed the best performance for TG. In the case of PLP mixtures for all three species, the 90:10 combination at 10% was the one with the highest internal bond. The oil palm waste (EFB or OPMF) in all three species studied, the 90:10 mixture at 10% was the one with the best IB values. Finally, TP with the three species, the 50:50 mixture was the one with the highest internal bond resistance. However, the adhesive proportion was different for each species, in CL it was 8%, in GA 8 and 10%, and in TG it was 10%.

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