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Internal bond strength of particle boards manufactured from a mixture of *Gmelina arborea*, *Tectona grandis* and *Cupressus lusitanica* with the fruit of *Elaeis guineensis*, leaves of *Ananas comosus* and tetra pak packages

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Abstract

Some countries with tropical climate produce a great variety of lignocellulosic waste from crops planted in small areas and also, urban areas produce a great amount of wastes fromTetra Paks packages without any kind of management. A possible solution is to incorporate these wastes into particleboards. The main objective of this work is to determine the relation in a mixture of particles from the empty fruit bunch of *Elaeis guineensis* (EFB), pineapple leaves (*Ananas comosus*) (PL), and Tetra Pak packages (TP) with 3 kinds of wood from forest plantations (*Gmelina arborea*, *Tectona grandis* and *Cupressus lusitanica*) commonly used for particleboards manufacturing. The proportions 50:50, 70:30, and 90:10 (waste:wood) with adhesive at 6, 8, and 10% (weight/weight) were tested for resistance regarding internal bond strength (IB). The results showed that the IB values

Resumen

Esfuerzo de cohesion interna de tableros de particulas fabricados de mezclas Gmelina arborea, Tectona grandis y Cupressus lusitanica con el fruto de Elaeis guineensis, hojas de Ananas comosus o empaques de tetra pak.

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 tetra pak package sin ningún tipo de manejo. El objetivo principal de este trabajo determinar la relación en una mezcla de partículas del fruto procesado de *Elaeis guineensis* (*BPF*), hojas de *Ananas cumosos* (*LP*) y empaques de tetra pak (*TP*) con 3 maderas de plantaciones forestales (*Gmelina arborea*, *Tectona grandis* and *Cupressus lusitanica*), comúnmente utilizadas en la fabricación de particleboards. Las proporciones de 50:50, 70:30 y 90:10 (residuo:madera)

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varied from 100 to 275 kPa in matrixes with PL, from 100 to 360 kPa for EFB and from 200-600 kPa in matrixes with TP. Furthermore, it was found that when the EFB and PL proportion decreases, the IB values increased, where mixture 90:10 with 10% adhesive showed the highest IB values. But for matrixes with TP, IB value is higher in proportions where the presence of wastes is greater, the 50:50 proportion with 10% adhesive showed the highest strength.

Key words: tropical species, internal bond, lignocellolose wastes, agricultural crop.

con adhesivo en 6, 8 y 10% (peso/peso) fueron probados su resistencia en cohesión interna (*IB*). Los resultados mostraron que los valores de *IB* variaron de 100 a 275 KPa en matrices con *LP*, de 100 a 360 KPa en componente de *BPF* y de 200-600 Kpa en matrices con *TP*. Así mismo fue encontrado que cuando disminuye la proporción de *BPF* y *LP*, los valores de *IB* aumentaron, siendo la mezcla 90:10 con 10% adhesivo con los valores de *IB* más altos. Pero las matrices con proporciones de *TP*, el valor *IB* es mayor en las proporciones con mayor proporción de este residuo, siendo la mezcla 50:50 con 10% las de mayor resistencia.

Palabras clave: especies tropicales, resistencia a cohesión, residuos lignocelulósicos, cultivos agrícolas.

Introduction

Many small countries in the tropical area have enviable climates, this makes possible the growth of 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. In 2007, more than 137 billion TP were delivered in every corner of the world (www.tetrapak.com).

Agricultural crops and packages for drink or food in the country suffer various problems: (i) Crops in general belong to many producers and are distributed throughout all country. (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 & 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). These boards are made from pure agricultural residues or from the combination of wood with other materials that have 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, (wood and lignocellulose material), of the empty fruit bunch of *Elaeis guineensis*, pineapple leaves (*Ananas cumosos*), 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.

Material and methods

Abreviations

TG: *Tectona grandis* **GA**: *Gmelina arbórea* **CL**: *Cupressus lusitanica* **EFB**: empty fruit bunch of *Elaeis guineensis* **OPMF**: oil palm mesocarp fiber of fruit **PLC**: Pineapple leaves from the crown **PLP**: Pineapple leaves from the plant **IB**: Internal bond strength (kPa) **PL**: Pineapple (*Ananas comosus*) leaves **TP**: Tetrak Pak package **UF**: urea-formaldehyde adhesive

Materials and origin: pineapple leaves from cropped plantation, fibers from the fruit of oil palm, Tetra Pak package (TP) and three different woody species were investigated. Pineapple leaves were obtained from a plantation of 20 months age where leaves were tested in two parts: leaves from the plant (PLP) and leaves from the crown (PLC). Oil palm fruits were collected in oil palm processing. Which was also tested in two parts: empty fruit bunch (EFB) and oil palm mesocarp fiber of fruit (OPMF), which is a waste produced after oil extraction from the fruit. TP were obtained from the recycling of postconsumer aseptic packaging located in our university. The three different species used as raw material in the particleboards fabrication were *Gmelina arborea* (GA), *Tectona grandis* (TG) and *Cupressus lusitanica* (CL). These species were collected from mature plantations. Plantation ages were: 9 yr-old in GA, 16 yr-old in TG and 22 yr-old in CL.

Materials preparation: Once the materials were collected, the next step was drying the materials. 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. In a previous research (Moya et al. 2010), it was established that the oil palm mesocarp fruit (OPMF) must be pre-treated by washing it with room-temperature water for an hour, stirring constantly to get the best reaction of the material to adhesives. Wood blisters were dried using the drying system detailed in Tenorio and Moya (2010). Then, particles were prepared by grinding them with a Retsch Knife Mill model SM100. The material was placed in a chamber with controlled temperature and relative humidity conditions (Darwin Chambers Compañy® model HT18002051) to reach a 6% content of relative humidity.

Matrixes and formulations: Each type of wood was mixed with each type of lignocellulosic residue separately (matrixes). Combinations wood with wood or waste with waste, 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 there were 5 different matrixes per each species: (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; for 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 2 mm in thickness using the finest material (particle size 0.7 to 1.5 mm long) and the inner layer, 10 mm 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 12 mm 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 a board density of approximately

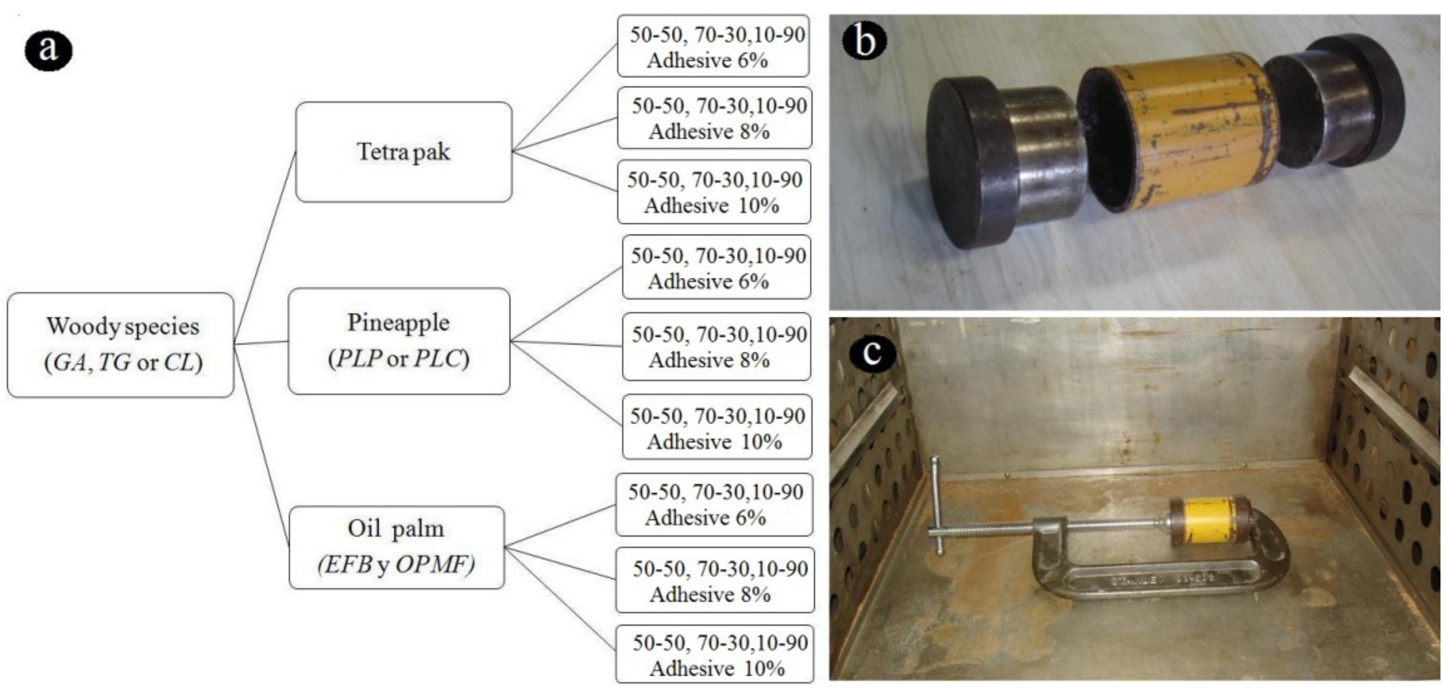

Figure 1. (a) Mixture of woody species with three different lignocelluloses residues. (b) metal rack utilized (c) press application during heating in the particleboards fabrication.

Figura 1. (a) Mezclas de especies maderables con tres tipos distintos de residuos lignocellulósicos. (b) parrilla de metal utilizada, (c) aplicación de presión durante el calentamiento de la mezcla.

1 g/cm^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 12 mm 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 °C. Finally, the samples were left for a 24 hour room-temperature-conditioning period.

Data analysis: a two-way analysis of variance (ANOVA) was applied (proportion of mixture and proportion of adhesive as study factors) for each species and for the IB values. 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, respectively.

Results

IB of the particleboard manufactured of Cupressus lusitanica (CL) and different wastes

In matrixes involving pineapple leaves, the resistance values went from 100 to 275 kPa. No tendency was observed (increase or decrease) with the proportions of the amount of pineapple leaves or adhesive (Figures 2a-2b). The CL-PLC-6 matrix (Figure 2a) did not show significant differences regarding IB between the three mixtures. Whereas in CL-PLC-8 differences were only found between 50:50 and 70:30, in CL-PLC-10, the IB value of the 90:10 mixture was significantly higher in relation to the 50:50 and 70:30 mixtures, but there were no differences among those two. When evaluating the IB differences within a single mixture, it was determined that in the 50:50 mixture, there were no significant differences between the three APs. But in the 70:30 mixture in CL-PLC-8 and CL-PLC-10 there were statistically higher IB values than the CL-PLC-6 mixture. The 90:10 mixture presented significant IB differences between CL-PLC-8 and CL-PLC-10.

On the other hand, for matrix CL-PLP (Figure 2b), the IB values of CL-PLP-6 were different than the 50:50 and 70:30 mixtures, while for CL-PLP-8 there were no IB differences for the three mixtures. In CL-PLP, the 90:10 mixture was significantly higher than the 50:50 and 70:30 mixtures. Regarding behavior within each mixture, it was determined that the 50:50 and 70:30 mixtures in CL-PLP-6 and CL-PLP-8 were statistically different. Finally, in the 90:10 mixtures, the IB value in CL-PLP-10 was statistically higher than CL-PLP-6.

In CL matrixes with oil palm empty fruit bunch (EFB or OPMF) it was observed that when reducing the palm component, the IB increases (Figures 2c and 2d). The IB values varied from 100 to 360 kPa. The CL-EFB-6 matrix did not show significant differences in any of the three mixtures (Figure 2c); while in CL-EFB-8 and CL-EFB-10, 70:30 and 90:10 mixtures had significantly higher IB values than the 50:50 mixture. The 70:30 and 90:10 mixtures did not show differences. As for the difference within each mixture (50:50, 70:30, and 90:10), no IB differences were found in the three APs. In the case of CL-OPMF (Figure 3d), CL-OPMF-6 matrix did not show differences between the three mixtures. In matrixes CL-OPMF-8 and CL-OPMF-10 the 50:50 mixture was significantly lower than the 70:30 and 90:10, but between 70:30 and 90:10 there were no differences. In the 50:50 mixture no differences were found between the 3 APs. In the 70:30 mixture, matrixes CL-OPMF-6 and CL-OPMF-8 had no significant differences, but in the CL-OPMF-10% matrix, the IB significantly increases in relation to the CL-OPMF-6 matrix. But this last proportion is not different than the CL-OPMF-8 matrix. In the 90:10 mixture, the IB value was significantly lower than the CL-OPMF-6, while the CL-OPMF-8 and CL-OPMF-10 matrixes were not statistically different.

Finally, in the CL-TP matrix (Figure 2e), the IB values went from 200 to 600 kPa. In matrixes CL-TP-6 and CL-TP-10, there were no differences between the three mixtures, while in matrix CL-TP-8 there were differences between the 70:30 and 90:10 proportions and the 50:50 mixture. Regarding differences in each mixture with the same AP, it was found that in the 50:50 mixture there were differences in the AP fiberboards, a significant IB increase when AP increases. In 70:30 mixtures there was no statistical difference between the three AP dosages and in the 90:10 mixtures, it was significantly higher for the CL-TP-10 matrix in comparison with CL-TP-6.

IB of particleboards manufactured of *Gmelina arborea* and different wastes

GA matrixes with pineapple leaves (Figures 3a and 3b) showed IB values between 100 and 300 kPa. In matrix GA-PLC (Figure 3a) in all three adhesive dosages, it is observed that when decreasing the PLC proportion, the IB increased. However, the statistical analysis did not find significant differences between particleboards with different APs. During evaluation, it was found that matrixes GA-PLC-6, GA-PLC-8 y GA-PLC-10 showed differences only between the 50:50 and 90:10 mixtures, the highest IB values are for the 90:10 mixture. Matrix GA-PLP (Figure 3b) shows a tendency to increase IB as PLP proportion decreases. When evaluating GA-PLP-6, differences were found only between the 50:50 and 70:30 mixtures, while the GA-PLP-8 matrix showed differences only between the 70:30 and 90:10 mixtures and the GA-PLP-10 matrix, the 90:10 mixture showed the highest IB value. As for the relation to AP under the same mixture, the 50:50 proportions did not show any difference between

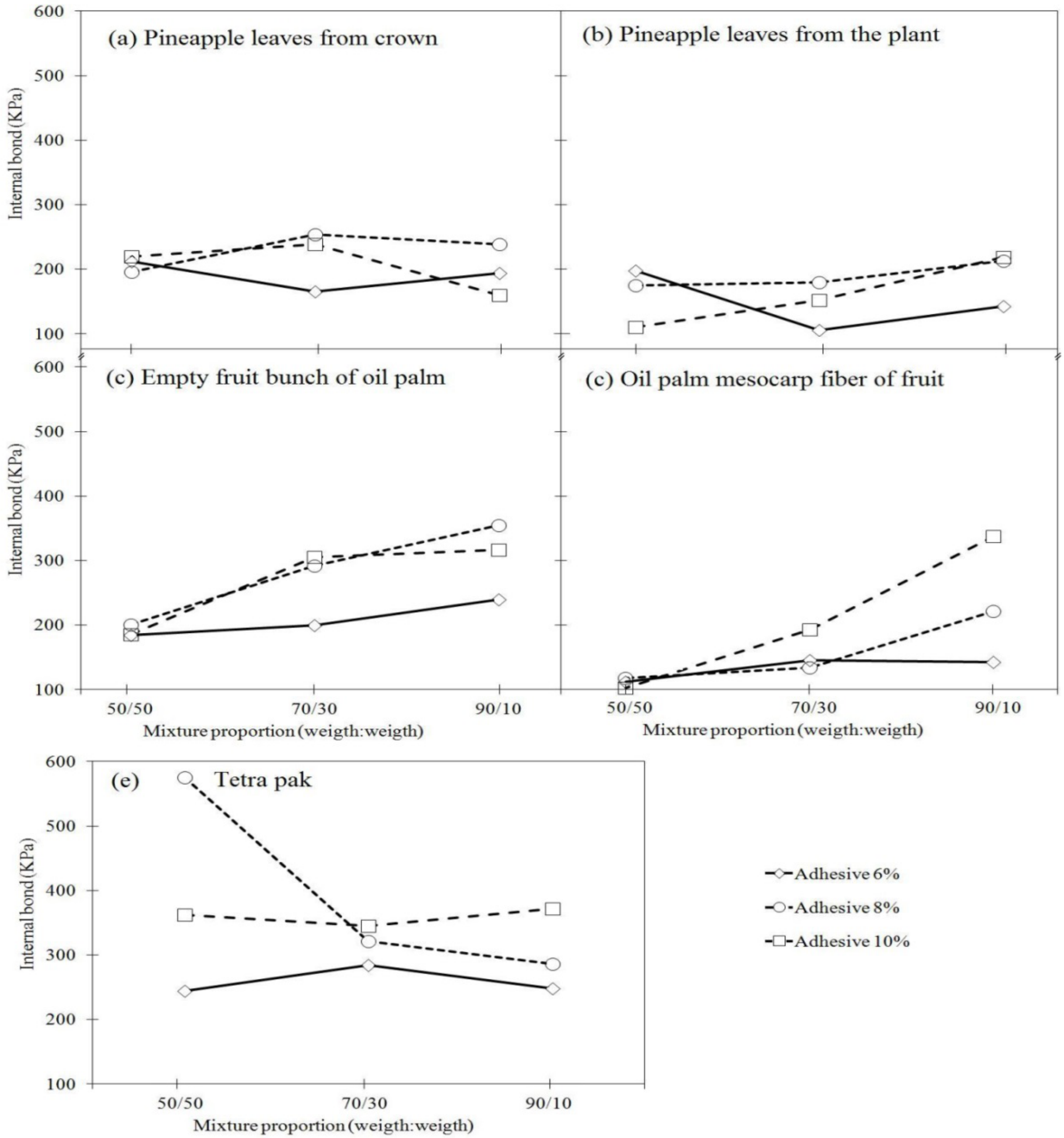

Figure 2. Internal bond strength of *Cupressus lusitanica* particleboards mixture with pineapple leaves, fiber from oil palm fruit and Tetra Pak package.

Figura 2. Esfuerzo de cohesion interna de tableros de particulas de *Cupressus lusitanica* fabricados con mezclas de hojas de piña, frutos de palma de aceite y empaques Tetra Pak.

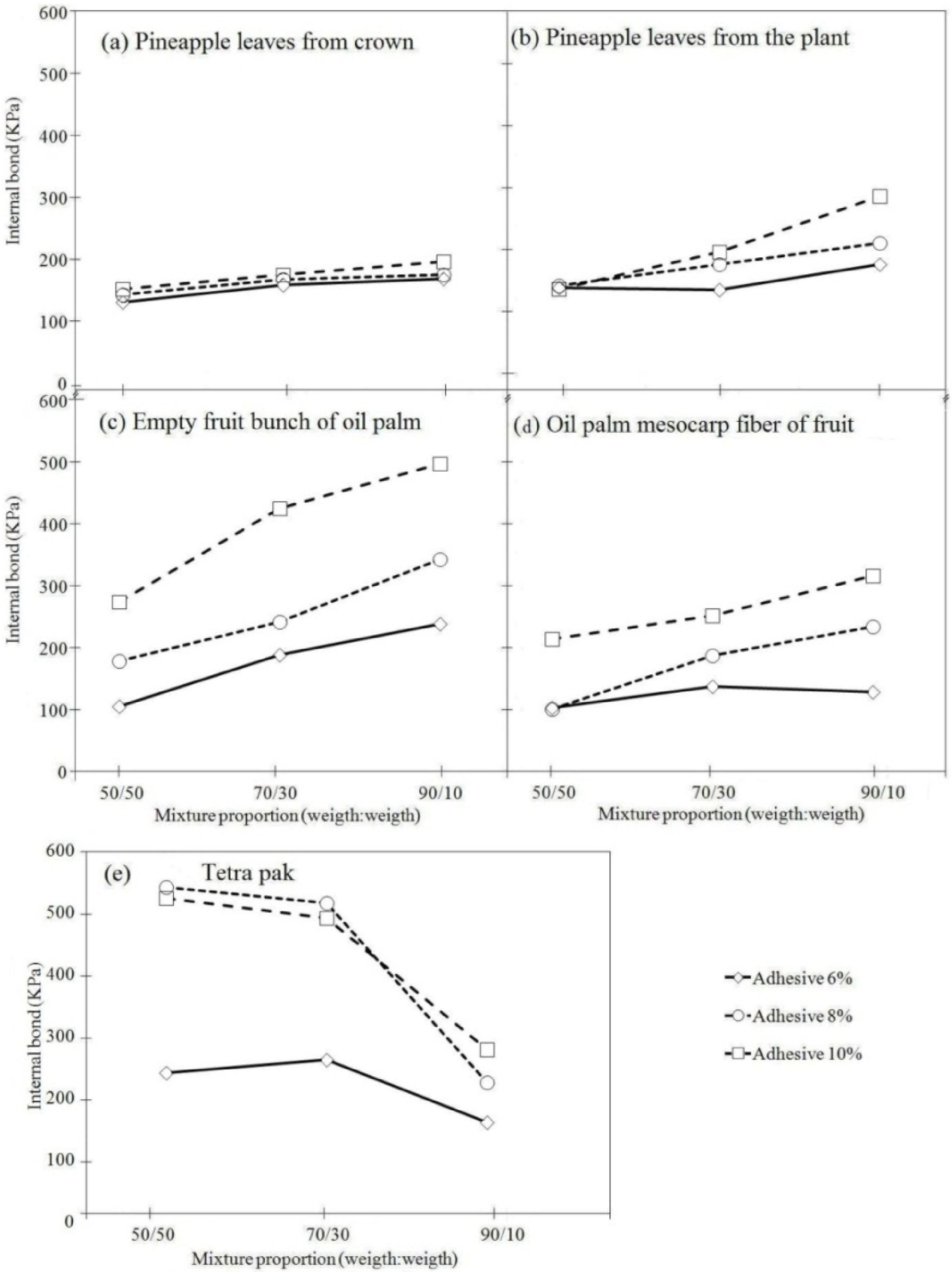

Figure 3. Internal bond strength of *Gmelina arborea* particleboards mixture with pineapple leaves, fiber from oil palm fruit and Tetra Pak package.

Figura 3. Esfuerzo de cohesion interna de tableros de particulas de *Gmelina arborea* fabricados con mezclas de hojas de piña, frutos de palma de aceite y empaques Tetra Pak.

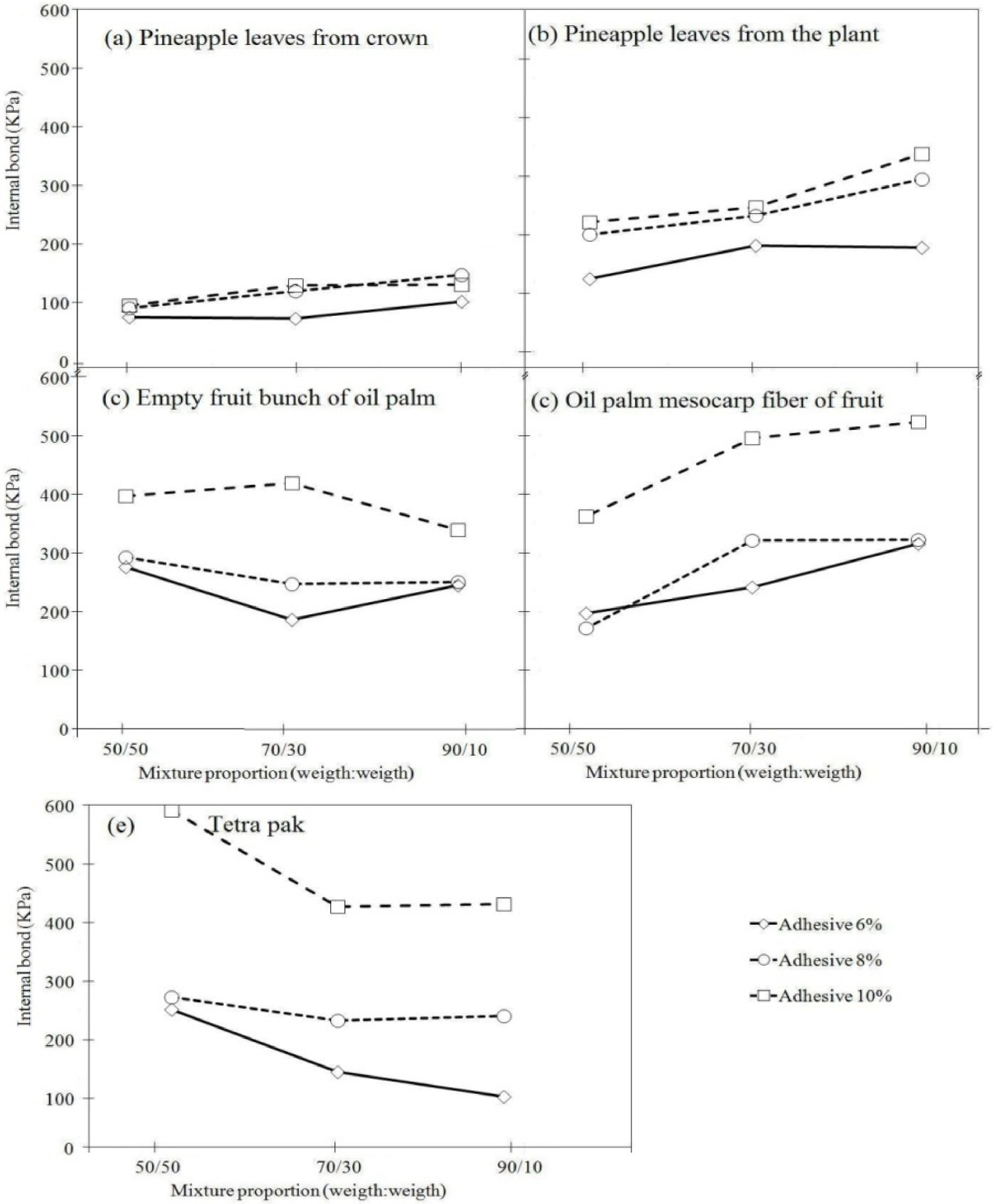

Figure 4. Internal bond strength of *Tectona grandis* particleboards mixture with pineapple leaves, fiber from oil palm fruit and Tetra Pak package.

Figura 4. Esfuerzo de cohesion interna de tableros de particulas de *Tectona grandis* fabricados con mezclas de hojas de piña, frutos de palma de aceite y empaques Tetra Pak.

particle boards with AP. The 70:30 mixture in GA-PLP-6 showed the lowest IB value in comparison with matrixes GA-PLP-10 and GA-PLP-8. In 90:10 mixtures, matrix GA-PLP-10 had an IB value significantly higher than matrixes GA-PLP-8 and GA-PLP-6 (between these two dosages there was no significant difference).

In matrixes with oil palm elements, IB values ranged from 100 to 550 kPa. In matrix GA-EFB (Figure 3c), IB increases by decreasing EFB at any AP. AP at 6% ranged significantly between 50:50 and 70:30 mixtures, while in 70:30 and 90:10 proportions, there were differences between the three mixtures, 90:10 showed the highest IB values. Regarding the evaluation of each blend, statistical analysis showed that the 50:50 mixture, in GA-EFB-10 matrix, the IB value is statistically higher in comparison with matrixes GA-EFB-8 and GA-EFB-6. In 70:30 and 90:10 blends, statistical differences in three APs were shown, GA-EFB-10 was the highest, followed by GA-EFB-8 and GA-EFB-6. In the GA-OPMF mixture, the tendency to increase IB as OPMF proportion decreased was kept (Figure 3d). Matrixes GA-OPMF-6, GA-OPMF-8 and GA-OPMF-10 showed statistical differences between 3 mixtures, 90:10 showed significantly higher IB values, and the 50:50 with the lowest values. When evaluating the behavior of the different adhesive proportions within each blend, it was determined that in the 50:50, 70:30 and 90:10 mixtures, statistical differences appeared between the three adhesive proportions, GA-OPMF-10 being the matrix with the highest IB values, followed by GA-OPMF-8 and finally GA-OPMF-6 with the lowest IB values.

A variation from 100 to 600 kPa was obtained from GA-TP matrixes (Figure 3e). Behavior was different than with the other lignocellulosic materials. A decrease in TP also decreased the IB values in the different AP. In the evaluation of the three proportions of one single adhesive percentage, it was found that the 50:50 and 70:30 mixtures did not show significant differences in IB values, but these two proportions are statistically different than the 90:10 mixture. In relation to the IB behavior in one single blend, it was found that in matrix GA-TP-6 it was statistically lower than in GA-TP-8 and GA-TP-10. But between GA-TP-8 and GA-TP-10 there were no significant differences in none of the three mixtures (50:50, 70:30, and 90:10).

IB of particle boards manufactured of *Tectona grandis* and different wastes

In matrixes of TG with pineapple leaves (Figures 4a and 4b), IB values ranged from 50 to 380 kPa. In matrix TG-PLC (Figure 4a), no tendency was found in the IB value with the increase or decrease of PLC. When evaluating the TG-PLC-6 matrix in all three mixtures (50:50, 70:30 and 90:10), no significant IB value differences were found, but for TG-PLC-8 a significant difference was found only between the 70:30 and 90:10 mixtures. For TG-PLC-10, the 50:50 mixture had an IB value significantly lower than the 70:30 and 90:10 blends, but between 70:30 and 90:10 blends there were no differences. Regarding the evaluation of adhesives under the same mixture, statistical analysis showed that 50:50 blends did not show significant differences among the three APs. But the 70:30 blend, in matrixes TG-PLC-8 and TG-PLC-10, the IB value was statistically higher than matrix TG-PLC-6. In mixture 90:10 only a difference in IB average was found between matrixes TG-PLC-6 and TG-PLC-8. In mixtures with PLP, once again, an increase in IB with the decrease in PLP proportion was noticed (Figure 4b).

IB obtained from the 50:50 mixture was significantly lower than 70:30 and 90:10 mixtures, but between 70:30 and 90:10 mixtures there was no difference. In matrixes TG-PLP-8 and TG-PLP-10, the significantly higher IB was found in mixture 90:10. In the 70:30 and 50:50 mixtures no significant differences were found. On the other hand, the TG mixture analysis with different AP combinations showed that for 50:50 and 70:30 mixtures, the IB value in matrixes TG-PLP-8 and TG-PLP-10 was statistically higher than TG-PLP-6. Whereas for the 90:10 mixture, it was found that the IB value for matrix TG-PLP-10 was significantly higher. There was no difference for matrixes TG-PLP-8 and TG-PLP-6.

In TG-EFB and TG-OPMF matrixes (Figures 4c and 4d) the IB values ranged from 150 to 500 kPa. In TG-EFB, a slight IB decrease was found with the reduction of the EFB proportion (Figure 4c). The TG-EFB-6 matrix showed significant differences in IB values between 50:50 and 70:30 mixtures, whereas TG-EFB-8 did not show IB differences between the three mixtures. TG-EFB-10 mixture only showed variations between 70:30 and 90:10 mixtures. In the average analysis for one mixture and different adhesive proportions, there are no IB differences between TG-EFB-8 and TG-EFB-6 in all the mixtures, but for these proportions, IB is statistically lower than the TG-EFB-10 mixture. In the TG-OPMF mixtures, IB behavior increased with the decrease of the OPMF proportion (Figure 4d). When establishing the average differences, it was found that in all the mixtures, matrixes TG-OPMF-6 and TG-OPMF-8 produce statistically lower IB than TG-OPMF-10 matrix. When assessing the behavior of adhesive proportions under one mixture, the TG-OPMF-6 mixture was the only one that showed a significant difference in IB between 50:50 and 70:30 dosages, whereas TG-OPMF-8 did not showed any variations in all three AP proportions. Matrix TG-OPMF-10 was significantly different than the 70:30 and 90:10 matrixes, but these last two did not showed any difference.

Finally, in matrix TG-TP, IB went from 100 to 500 kPa (Figure 4e) and there is a decrease in IB with the TP percentage reduction. The statistical analysis revealed that TG-TP-6 and TG-TP-10 presented significant differences in IB between 50:50 mixture with 70:30 and 90:10, but between 70:30 and 90:10 mixtures there was no difference. For matrix TG-TP-8 no differences were found. On the other hand, in the adhesive proportion under one single mixture, it was found that the 50:50 mixture of matrix TG.TP-10, the IB value was statistically higher than TG-TP-8 and TG-TP-6. In mixtures 70:30 and 90:10, IB values in the three APs used were statistically different, TG-TP-10 being the matrix with the highest IB value and TG-TP-6 with the lowest values.

Discussion

IB values found in the different lignocellulosic residue matrixes are slightly higher than the values found in particleboards made out of wheat and pine, manufactured according to 50:50 and 75:25 mixtures (wheat waste:pine) with urea-formaldehyde adhesive (UF) at 10% (Grigoriou, 2000; Yasar et al. 2010), which on average presented 160 and 70 kPa respectively. However, particleboards manufactured with pineapple leaves, oil palm or TP have lower IB values reported for particleboards made with *Eucalyptus camaldulensis* (886 kPa), *Prosopis juliflora* (943 kPa), *Tamarix stricta* (886 kPa), and *Phoenix dactylifera* (576 kPa) (Ashori and Nourbakhsh, 2008).

Another worth mentioning fact is that particleboards involving pineapple show the lowest IB values (Figures. 2a, 3a, 3b, 4a & 4b) followed by those manufactured with oil palm (Figures 2c, 3d-d, 4c and 4d). The ones with the highest resistance are those made out of TP (Figures 2e, 3e, & 4e). 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 et al. 1997; Moya et al. 2015); unlike pineapple, which presents a pH 4 or 5 with a lower amount of cellulose and lignin (Moya et al. 2015; Saifuddin & Kumaran, 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 et al. 1998).

In pineapple and oil palm residues, the mixture with the highest IB 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, IB tends to increase when the wheat hay 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 IB resistance with the AP variation (Figures 2, 3 & 4). Particleboards manufactured with 10% adhesive, presented the highest IB 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 (Figures 2e, 3e & 4e) showed a different behavior than pineapple or oil palm. The increase in the TP proportion on the board matrix increases resistance (Figures 2e, 3e & 4e). 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 et al. 2011). Xing et al. (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 and therefore higher IB values (Korkmaz et al. 2009).

Conclusions

The IB values 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 IB values. 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 IB 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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