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Evaluation of *Hesperaloe funifera* pulps obtained by a low energy consumption process as a reinforcement material in recycled pulps

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Abstract

The aim of this work is to study the reinforcement capacity of pulps obtained from *Hesperaloe funifera* using a simple and low energy consumption process (chemi refiner mechanical pulping) once they are added in different percentages to recycled pulps from newspaper and from old corrugated containers (OCC). *Pinus radiata* kraft pulp was used as a referent reinforcement material.

H. funifera acted as a reinforcement material in newspaper and OCC recycled pulps, improving their optical and mechanical properties. While a 25% of *H. funifera* was the optimal amount added to reinforce the OCC pulp, only a 10% was needed for newspaper pulp. However, the OCC optimal mixture was better reinforced as it showed higher increase in all properties than the optimal newspaper mixture, apart from tensile index. Finally, all mixtures with *P. radiata* kraft pulp produce handsheet with lower properties, apart from tear index, suggesting than *H. funifera* is a better reinforcement material.

Key words: *Hesperaloe funifera;* reinforcement fibers; recycled pulp; newspaper; old corrugated containers.

Resumen

Evaluación de pastas de *Hesperaloe funifera* obtenidas con un proceso de bajo consumo energético como material de refuerzo de pastas recicladas

El objetivo de este trabajo es estudiar la capacidad de refuerzo de pastas de *Hesperaloe funifera* obtenidas mediante un proceso simple de bajo consumo energético (pasteado químico-mecánico de refino) una vez añadidas en diferentes porcentajes a pastas recicladas de periódicos y de cartón ondulado (OCC). Se utilizó como material de refuerzo de referencia pasta kraft de *Pinus radiata.*

H. funifera mejoró las propiedades ópticas y mecánicas de todas las pastas recicladas estudiadas, demostrando su capacidad de refuerzo. Mientras que un 25% de *H. funifera* fue la cantidad óptima para reforzar la pasta de OCC, sólo un 10% fue necesario para la pasta de periódicos. Sin embargo, la mezcla óptima de OCC mostró un mayor incremento en todas las propiedades que la mezcla óptima de periódicos, a excepción del índice de tracción. Por último, todas las mezclas de pasta kraft de *P. radiata* proporcionaron hojas con menores propiedades mecánicas, a excepción del índice de desgarro, lo que sugiere que *H. funifera* es un material de refuerzo más eficaz.

Palabras clave: *Hesperaloe funifera;* fibras de refuerzo; pastas recicladas; periódicos; cartón ondulado.

Introduction

Nowadays, newspaper is usually made with thermomechanical pulp from softwood species, deinked pulp from old newspapers or a mixture of both. However, old corrugated container can be also used as raw material for this end (Lee *et al.*, 1999; Van Tran, 2002). This material usually contains a high percentage of kraft fibers, therefore, when it is recycled, the mechanical properties of the produced paper could be better than those obtained from conventional sources such as newspaper recycled pulps. However, because fibers lose mechanical properties during the recycling circles and also there is a trend towards increasing paper machine speeds and reducing raw material consumption by decreasing the basic weight of the paper, the addition of a reinforcement material to conserve

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the paper strength is recommended (Mansfield *et al.*, 2004). The reinforcement material mainly increases wet-web strength of the blend and mechanical properties of the sheet, improving runnability on the paper machine and on the printing press (Horn *et al.*, 1992). Whereas, short fibers and fines from recycled pulps form a good printing base (Lumiainen and Partanen, 1997).

In Spain, the recycling rate (recycled paper consumption as raw material to paper and cardboard consumption ratio) has increased a 21.5% in the last years. This growing demand of recycled pulp added to the aforementioned tendency of producing quicker and thinner newspaper, justify the search of material which act as reinforcement of recycled pulps.

Normally, softwood kraft pulps such as those obtained from *Pinus radiata* are used as a reinforcement material due to its long fibers and good papermaking properties. The reinforcement ability of this kind of pulp is improved by refining the fibers to produce external fibrillation, secondary wall delamination and increasing collapsibility and flexibility (Mansfield *et al.*, 2004; Lumiainen and Partanen, 1997). However, other raw materials such as *Hesperaloe funifera* has been considered to be a possible reinforcement material due to its long and slim fibers that would provide more fiber surface area bonding (Fairbank and Detrick, 2000).

H. funifera is a non-wood raw material native from the Chihuahuan desert of Northern Mexico. McLaughlin (2000) evaluated its potential as a papermaking raw material and reported that its pulps are as good as those made from high-cost pulps (softwood kraft or abaca and sisal soda-anthraquinone pulps). Moreover, due to its low-irrigation requirement, *H. funifera* might grow in areas with scant water resources. The first harvest takes 5 years to develop in full and the plant gives a new harvest every 3 years afterwards. High-density plantations (27,000 plants per hectare) can yield approximately 20 t ha^{-1} yr of dry biomass, after the initial crop (Wong and McLaughlin, 2000).

Another advantage of using *H. funifera* at the pulp and paper industry is its low lignin content that could reduce energy and chemicals consumption during pulping process. In addition, obtained pulps show outstanding values in burst and tensile indexes which suggest that *H. funifera* pulp could be used as a reinforcement pulp without refining (Fairbank, 2000). Taken into account that refining is one of the process which consumes more energy in pulping, the use of this material without refining suppose an advantage compared with other alternatives. This is also important since many paper mills that produce mechanical paper grades have little or no capacity available for refining their reinforcement pulp.

Although there are some studies about the use of *H. funifera* as reinforcement material as it has been mentioned above, few of them deals with its use to reinforce recycled pulps from newspaper and even less from OCC. Moreover, a *H. funifera* CRM (chemi refiner mechanical) pulping, which could be an efficient and environmental friendly process, has been never used before for this end.

Based on these statements, the objective of this work is to use an efficient, simple and environmental friendly pulping process to produce high quality *H. funifera* pulps to be used as a reinforcement material in the production of newspaper. For this end, different percentages of *H. funifera* CRM pulps have been added to newspaper and OCC recycled pulps. The *H. funifera* pulp has been used without refining to reduce, as much as possible, the global energy consumption and without bleaching to limit the investment in pulping installations and operational costs. Also, the reinforcement capacity of *P. radiata* kraft pulp has been evaluated to compare the reinforcement efficiency of *H. funifera* with a reference material considered as a standard.

Materials and Methods

Characterization of raw materials

Newspapers and OCC were supplied by a Spanish paper mill. *H. funifera* were kindly provided by University of Valencia (Spain) and *P. radiata* chips were supplied by a Spanish pulp mill.

The chemical composition of *H. funifera* and *P. radiata* were analyzed as follow: ash content (TAPPI T 211 om-93), hot water extractives (TAPPI T 207 om-93), acetone extractives (TAPPI T 204 om-88), lignin (TAPPI T 222 om-88) and holocellulose (Wise *et al.*, 1946). Fiber length of both species was measure by projection and fiber width was directly measured from the pulp suspension using a microscope with a Visopan screen.

Pulping

Hesperaloe funifera pulp

A CRMP (chemi refiner mechanical pulping) was selected to produce the *H. funifera* reinforcement pulp.

H. funifera was first cut into pieces of a maximum of 10 cm and immersed in a 0.8% SO_3Na_2 solution during two hours at room temperature. Then the material was defibrated in a 12" Sprout Waldron refiner provided with a recirculation system which controls the temperature of the impregnation liquor. Defibering was carried out in a single pass by the refiner with 0.5 mm of cleavage and a 0.8% SO_3Na_2 solution at 70°C which was recirculated into the system. After defibering, the pulp suspension was washed to remove the excess of chemicals and passed through a 0.25 mm screen to remove rejects.

Pinus radiata pulp

Kraft cooking of *P. radiata* chips was done in a 26 L batch reactor furnished with a system for recirculation and heating of the cooking liquor. Previous to cooking, the chips were steamed for 5 min to facilitate impregnation of chemicals. The cooking temperature was controlled by a computer running specially developed software. The cooking conditions were: 20% active alkali, 25% sulphidity, 4 L kg^{-1} liquor/wood ratio, 170°C cooking temperature, 40 min to cooking temperature and 60 min at cooking temperature. These conditions correspond to an H-factor of 940.

Recycled pulps

Newspaper and OCC recycled pulps were obtained in a 50 L laboratory pulper, powered with 2CV engine and fitted with helical rotor for high consistency pulping. Operational conditions were: 10 min, 50°C and 15% of consistency. After pulping, the newspaper recycled pulp was treated in a cyclonic cleaner. The OCC pulp did not need depuration.

The fibrous compositions of both pulps were determined using an optical microscope (Vanox AH3 Olympus) connected to a digital camera Color View III.

Pulp preparation and handsheet testing

Recycled pulps from newspaper or OCC were mixed with the *H. funifera* CRM pulp in three different percentages (Table 1). The recycled pulps were also reinforced with *P. radiata* kraft pulp in order to compare the reinforcement capacity of *H. funifera* with a referent reinforcement material. All mixtures were disintegrated following the standard ISO 5263-1 and the Schopper-Riegler (°SR) was determined according to ISO 5267-1.

Table 1. Prepared Pulps

Mixture	Newspaper recycled pulp (%)	OCC recycled pulp (%)	*H. funifera* CRM pulp (%)	*P. radiata* kraft pulp (%)
H[a]	—	—	100	—
P[b]	—	—	—	100
NP[c]	100	—	—	—
OCC[d]	—	100	—	—
NP-H10	90	—	10	—
NP-H25	75	—	25	—
NP-P10	90	—	—	10
NP-P25	75	—	—	25
OCC-H10	—	90	10	—
OCC-H25	—	75	25	—
OCC-P10	—	90	—	10
OCC-P25	—	75	—	25

[a] H: *Hesperaloe funifera* CRM pulp; [b] P: *Pinus radiata* kraft pulp; [c] NP: Newspaper recycled pulp; [d] OCC: Old Corrugated Container recycled pulp.

Handsheets were prepared from the individual pulps and from the different mixtures of recycled — virgin fibers in accordance with ISO 5269-2. Characterization was made in terms of apparent bulk density, tensile index, burst index, tear index (ISO 5270) and brightness (ISO 2470).

Results

Reinforcement raw material and pulps characterization

As it has been mentioned above, *H. funifera* has been considered as a reinforcement material due to its fibers properties and its high productivity by hectare in substitution of the expensive softwood kraft pulp (*P. radiata*). Chemical composition and biometric analysis of both raw materials are shown in table 2. Fibers of *H. funifera* are longer and thinner than those of *P. radiata* and, consequently, their slenderness (L/D ratio) is much higher.

From table 2, it can be observed that *H. funifera* has higher ash, extractives and hollocelulose contents than *P. radiate*. On the other hand, lower lignin content (around of one third of the amount in *P. radiata*) was found for this non-wood raw material.

Figure 1 shows the *H. funifera* CRM and *P. radiata* kraft fibers. As it can be observed, both pulping processes provided pulps with good fiber separation and

Table 2. Chemical composition and fiber dimensions of *P. radiata* and *H. funifera*

	H. funifera	*P. radiata*
Ash 525°C (%)	5.2	0.3
Hot water extractives (%)	15.0	2.0
Acetone extractives (%)	2.2	0.9
Lignin (%)	7.2	25.5
Holocellulose (%)	72.5	69.2
L: Fiber length (mm)	4.2	3.2
D: Fiber diameter (μm)	7.2	50
L/D ratio	580	64

without high degradation. In addition, this Figure confirms the higher slenderness of *H. funifera* than *P. radiata* fibers.

The composition of the pulps obtained by recycling waste newspaper and OCC were determinate using an optical microscope and the results are shown in table 3. It can be observed that a 90% of the newspaper recycled pulp consisted of softwood fibers from pine and spruce species which improve mechanical resistances. In addition, a 65% of the fibers came from mechanical pulps which provide paper with good optical properties for printing processes. On the other hand, around of 80% of OCC pulp consisted of chemical pulps, most of them (50% of the total) came from softwood species.

Paper properties of reinforced recycled newspaper pulps

Handsheets were formed from the different mixtures assayed (Table 1) using *H. funifera* CRM or *P. radiata* kraft pulps to improve the quality of the recycled newspaper. The changes in the mechanical properties (apparent bulk density, tear, tensile and burst indexes) of the handsheets are shown in Figure 2. Moreover, the effect on brightness caused by the addition of the reinforcement materials can be observed in Figure 3.

Paper properties of reinforced recycled OCC pulps

Mechanical and optical properties of handsheets formed from recycled OCC and the reinforcement pulps (Table 1) were measured. Figure 4 plots the apparent bulk density, tear, tensile and burst indexes while Figure 5 shows the brightness of the formed handsheets.

Discussion

Reinforcement raw material and pulps characterization

The high slenderness (L/D ratio) of *H. funifera* fibers provides more fiber surface area bonding, suggesting that this non-wood raw material should be a better reinforcement material than *P. radiata* (Table 2).

H. funifera has high hollocelulose content (Table 2) that guarantees a good pulping yield. Furthermore, its low lignin content suggests that a CRM pulping would be an adequate process to produce pulp, since this raw material does not need a strong delignification process. This process combines the advantages of both mechanical and chemical pulping, maintaining high fiber

a) b)

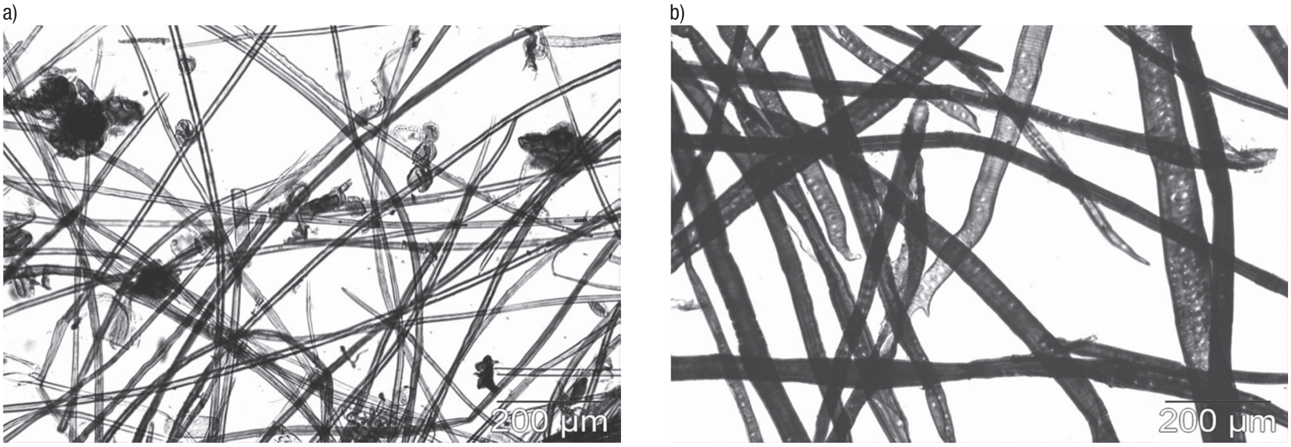

Figure 1. Fibers from: (a) *H. funifera* CRM pulp and (b) *P. radiata* kraft pulp.

Table 3. Composition of newspaper and old corrugated containers (OCC) recycled pulps

	Softwood chemical fibers	Hardwood chemical fibers	Gramineae semi-chemical fibers	Softwood mechanical fibers
Newspaper recycled pulp	25% *Pinus sylvestris* and spruce	10% *Eucalyptus globulus*, and poplar		65% spruce
OCC recycled pulp	50% *Pinus sylvestris*, *Pinus pinaster* and spruce	30%[a] *Eucalyptus globulus*, beech and poplar	Trace Straw	20% spruce

[a] Chemical and semi-chemical hardwood fibers.

length and good mechanical properties without producing high delignification, which implicates a high pulp yield and low solids content in the generated effluents. On the contrary, a kraft process should be appropriate to *P. radiata* pulp since this material needs stronger delignification due to its high lignin content. Therefore, these were the pulping processes selected for each raw material in this work.

Regarding the characteristics of the studied recycles pulps, it should be mentioned that despite the initial mechanical resistance of both newspaper and OCC recycled pulps (suggested by their composition), the subsequent recycling cycles and the possible incorporation of low quality old papers could reduce the strength being recommended the addition of a reinforcement material.

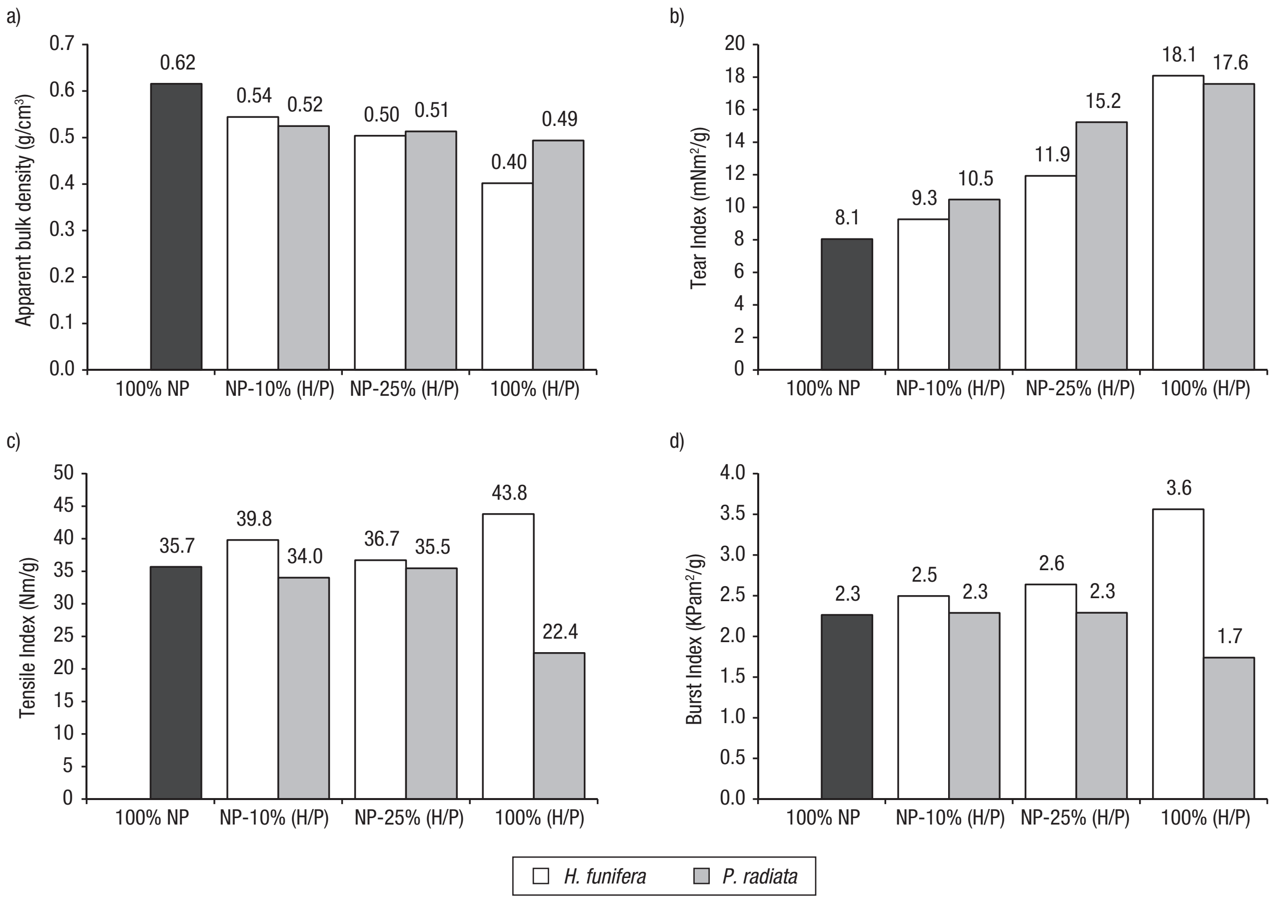

Figure 2. Reinforcement of recycled newspaper pulps. Effect on (a) apparent bulk density, (b) tear index, (c) tensile index and (d) burst index.

Paper properties of reinforced recycled newspaper pulps

In Figure 2a, it can be observed that the highest apparent bulk density was found in the newspaper recycled handsheets (0.62 g cm^{-3}), being this value similar to those observed in commercial recycled papers. Although *H. funifera* handsheets showed the lowest value, the mixtures reinforced with this material presented similar apparent bulk density (0.50-0.54 g cm^{-3}) than those obtained adding *P. radiata* pulps. This behavior is coherent with the fiber distribution of the raw materials. The long fibers of *H. funifera* and *P. radiata* unrefined pulps do not form sheets as compact as those formed from newspaper recycled pulp which consisting of a mixture of fibers and fines. Taking into account these lower density values, it could be concluded that the addition of both reinforcement materials provides a product with better bulk density, which is an advantage for printing grades of paper.

H. funifera CRM pulp showed higher tear index than newspaper recycled pulp (Figure 2b). This fact can be explained since tear index is related to fiber degradation and the successive recycling and papermaking cycles cause fibers damages and a loss of strength to the paper. Consequently, the reinforcement of newspaper recycling pulp with *H. funifera* CRM pulp improves the tear index and the extent of the improvement depends on the percentage of reinforcement pulp. However, the reinforcement capacity of *H. funifera* pulps is lower than that of *P. radiata* kraft pulps according to tear index, the reference pulp used as reinforcement material.

Tensile and burst indexes, directly related to link capacity between fibers, were found much higher for

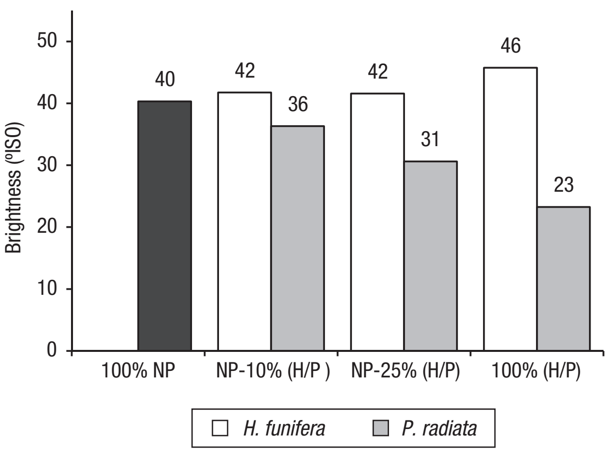

Figure 3. Reinforcement of recycled newspaper pulps. Effect on brightness.

H. funifera CRM pulp than for *P. radiata* kraft (Figure 2c-2d). This statement suggests that *H. funifera* pulps could be used as an effective reinforcement pulp even without refining. These results are similar to those found by Fairbank and Detrick (2000) who studied the effect of these materials to reinforce mixtures of stone ground wood and thermo mechanical pulps.

From Figure 2c and 2d it can be concluded that the addition of *H. funifera* pulps to newspaper recycled pulp increased tensile and burst indexes while the addition of *P. radiata* pulp did not cause almost any effect. Furthermore, an increase from 10 to 25% in the *H. funifera* pulp addition, decreased the tensile index (Figure 2c) while the burst index remained approximately constant (Figure 2d). This result is not in concordance which those obtained by Fairbank and Detrick (2000), who found an improvement in tensile and burst indexes when the added percentage of *H. funifera* increased from 10 to 25%. However, these authors used chemical pulp instead of CRM pulp to reinforce mechanical pulps.

Brightness, which is an important parameter in newspaper and other printing grades, is showed in Figure 3. Although *H. funifera* pulp was no previously bleached, it had higher brightness (46% ISO) than the recycled newspaper pulp (40% ISO). Therefore, an addition of 10% or 25% of *H. funifera* caused an increase of 2 points % ISO in brightness. For this paper grades, the addition of unbleached *P. radiata* kraft pulp is not appropriate to improve the brightness due to its initial low brightness value.

Based on the mechanical and optical properties, *H. funifera* CRM pulp, used without bleaching and refining, exhibited to be a possible reinforcement pulp which also preserve brightness and improve bulk, two important properties in newspaper production. Moreover, a 10% of *H. funifera* was an adequate percentage to reinforce the recycled newspaper pulp. This mixture also showed better drainage characteristics than the recycled pulp (55° vs. 61° Schopper Riegler) what could suppose less energy consumption in the dryer section and/or higher paper machine speed. Finally, the referent reinforcement material (*P. radiata*) did not show better increases in any properties apart from tear index.

Paper properties of reinforced recycled OCC pulps

The highest apparent bulk density (Figure 4a) was found in the OCC handsheets (0.59 g cm^{-3}), while the addition of the studied reinforcement materials caused

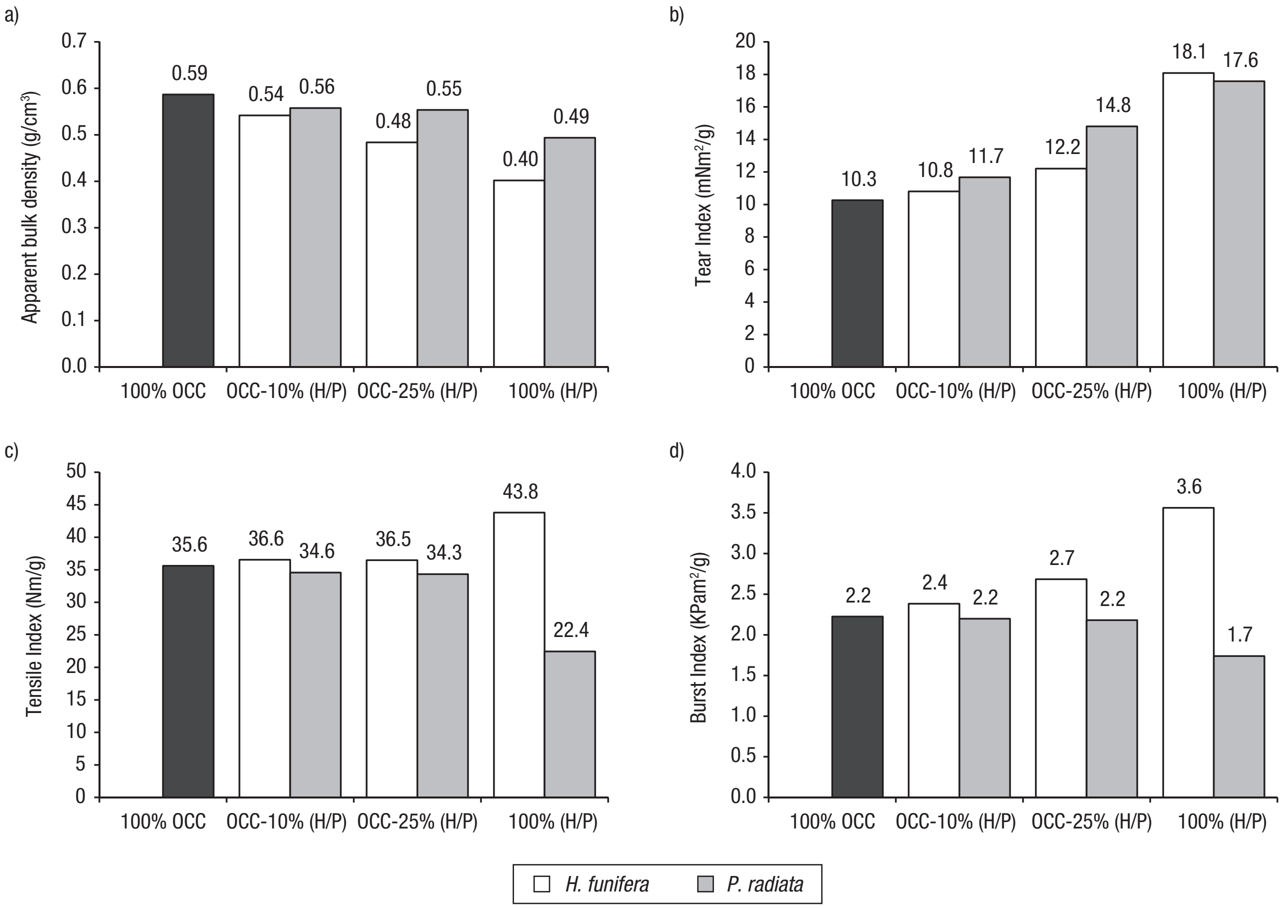

Figure 4. Reinforcement of recycled old corrugated container pulps. Effect on (a) apparent bulk density, (b) tear index, (c) tensile index and (d) burst index.

only a moderate reduction in this parameter, apart from in the case where a 25% *H. funifera* pulp was added. These results suggest that, for OCC recycled pulps, the bonding capacity of the mixture did not improve with the addition of the virgin fibers.

As it was expected, (Figure 4b), recycled OCC pulps increased its tear index value when they were reinforced with *H. funifera* CRM pulp or *P. radiata* kraft pulp. The highest increase found was 44%, corresponding to an addition of a 25% of *P. radiata* kraft pulp, while with an addition of 25% of *H. funifera* CRM pulp only a 18% of improvement was observed. However, these increases were lower than those observed when newspaper was reinforced using the same amount of *H. funifera* (47%) and *P. radiata* (88%) pulps. This fact could be explained taking into account that the effect of adding reinforcement materials is more pronounced in newspaper recycled pulps, since this pulp showed a low initial tear index (Figure 2b).

Tensile and burst indexes of recycled OCC pulp only were improved when *H. funifera* CRM pulp was the reinforcement material (Figures 4c and 4d). The addition of *P. radiata* kraft pulp maintains the same burst index and even reduces the tensile index. This behavior was similar to that observed when newspaper recycled pulp was reinforced with the same materials. However, in the case of OCC pulp, an increase in the addition of *H. funifera* pulp from 10% to 25% improved mechanical sheets properties, increasing the burst index by up to 23% and maintaining almost constant the tensile index (3%).

Figure 5 shows that brightness of OCC pulp was increased when *H. funifera* CRM pulp was added as a reinforcement material while it was decreased when *P. radiata* kraft pulp was added. This fact was also observed when newspaper recycled pulp was reinforced using these materials, although all mixtures obtained from newspaper showed better final brightness because of its higher initial value. On the other hand, an increase

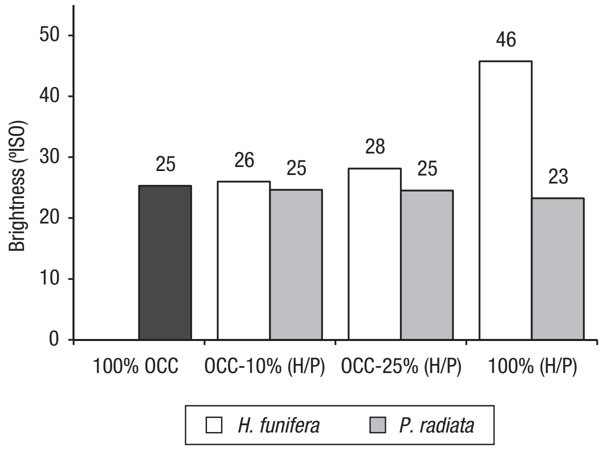

Figure 5. Reinforcement of recycled old corrugated container pulps. Effect on brightness.

in the addition of *H. funifera* from 10 to 25% to OCC pulp showed a continuously increase in the brightness contrarily what it was found for newspaper recycled pulp. This fact could be explained due to the lower brightness of OCC pulps which could be more affected by the addition of a pulp with a relative high brightness.

It can be concluded that a 25% of *H. funifera* CRM pulp was the best assayed solution to reinforce recycled OCC pulps, since a low percentage of *H. funifera* provided mixtures with lower brightness, tear index and burst index. Furthermore, adding *P. radiata* pulp, lower optical and mechanical properties (apart from tear index) was also observed compared to *H. funifera*.

Conclusions

The CRM pulping (a simple process which does not require high investment) provided a *H. funifera* pulp with high mechanical and good optical properties. This pulp, without refining and bleaching, acted as a reinforcement material in recycled newspaper and old corrugated containers, improving brightness and mechanical properties (tear, tensile and burst). *H. funifera* CRM pulp was a better reinforcement material than *P. radiata* kraft pulp (a referent reinforcement material) since a higher increase in all properties was found, apart from tear index.

A 10% of *H. funifera* CRM pulp was enough to increase brightness (2 points % ISO) and also tear (15%), burst (9%) and tensile (11%) indexes in recycled pulp from newspaper. A higher percentage of *H. funifera* pulp, did not increase significantly these properties apart from the tear index. On the other hand, a 25% of *H. funifera* was the best solution to reinforce the old corrugated container pulp, finding an increase in brightness (3% ISO) and tear (18%), burst (23%) and tensile (3%) indexes. Comparing the best mixtures obtained when newspaper and OCC pulps were reinforced, it can be concluded that, in general, OCC pulps showed higher increases in all mechanical and optical properties than newspaper recycled pulp, apart from tensile index.

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