Technical study on the production of blocks with composites of cement-wooden wastes from pallets of *Pinus sp*

Estudio técnico de la producción de bloques compuesto de cemento y tarimas recicladas de *Pinus sp*

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Abstract

A composite between particles obtained residual pallets of *Pinus sp* and cement was manufactured. Also, three methods were performance for wood particles: hot water washed, unwashed and unwashed with calcium carbonate ($CaCO_3$). Different concrete-wood particle ratios were tested. Curing time was evaluated with ultrasonic pulse velocity (USV) and density of composites. Water absorption, module of rupture (MOR) in flexion, abrasion strength and resistance to decay by fungi attack were too determined. Results showed that using USV and density, curing occurs within 8 days. Moisture absorption ranges15 and 22% and decreases with decreasing of the amount of particles. MOR ranged from 0.40 a 1.23 MPa and the blocks with unwashed wooden particles and with $CaCO_3$ addition had the greatest significant differences. In abrasion strength, blocks with unwashed wooden particles reported the best results. Finally, it was concluded that mixture with proportion of 60:40 (concrete:wood) and $CaCO_3$ had the best performance and were not attacked by fungi decay.

Keywords: Construction material, wastes, absorption, concrete blocks, Costa Rica.

Resumen

Fue fabricado un compuesto de partículas de *Pinus sp* proveniente de tarimas y 3 métodos fueron practicados en las partículas: lavado con agua caliente, sin lavar y sin lavar con adición de carbonato de calcio. Diferentes proporciones de cemento–maderas fueron probadas. El endurecimiento fue evaluado por la velocidad de pulso ultrasónico (VPU) y la densidad. Así mismo fue evaluado la absorción de agua, módulo de ruptura (MOR) en flexión, resistencia a la abrasión y resistencia al ataque de hongos de pudrición. Los resultados mostraron que utilizando VPU y densidad, el endurecimiento ocurre a los 8 días. La absorción de humedad fluctúa entre 15 y 22% y disminuye con la disminución de la cantidad de partículas de madera. El MR varió de 0,40 a 1,23 MPa y los adoquines con partículas de madera sin lavar y agregado cal presentaron las mayores diferencias significativas. En la resistencia a la abrasión, los adoquines con partículas de madera sin lavar reportan los mejores resultados. Finalmente se concluyó que la mezcla con proporciones de 60:40 (concreto: madera) y agregando cal presenta el mejor comportamiento y no son atacados por los hongos de pudrición.

Palabras claves: Material de construcción, residuos, absorción, adoquines, Costa Rica.

Introduction

There are some concrete products that perform specific functions rather than structural, for example concrete blocks, allowing people and vehicles to displace through an infrastructure network such as roads, sidewalks, parking lots, floors and even as decorative elements in terraces allowing excellent finishes (Mooneghi, Irwin & Chowdhury, 2014). The block

covers surfaces through individual pieces preventing floods or water runoff during rainy season due to permeable characteristics (Park, Sandoval, Lin, Kim & Cho, 2014).

Constant growth of world population and construction demand has caused several problems, among which environmental degradation is highlighted by wastes generation (Torkaman, Ashori, & Momtazi, 2014). Likewise, demolitions of structures also produce a high amount of waste, despite the environmental regulations and laws created to improve the management of these (Ashori, Tabarsa & Amosi, 2012a).

Antagonistically, wood processing industries produce wastes (sawdust, chips and short pieces), which are often simply discarded or have a low cost for sale despite its potential for use (Serrano & Moya, 2011). In addition to this problem, in international trade there is a heavy use of pallets, which help the efficient and reliable transport of goods. However, they have a short life and therefore consume large amounts of resources and in turn produce around 2-3% of existing wastes (Buehlmann, Bumgardner & Fluharty, 2009), which after use it has no proper elimination process.

In the next years, different industries, such as construction and forestry, are challenged to incorporate sustainability into their production processes, either finding new and more environmentally friendly raw materials and environmental products and/or contribute to CO_2 reduction into the atmosphere (Torkaman et al., 2014). A possible solution together the construction and forestry sectors are to implement concrete and wood products, as a substitute for the petrous aggregates (Serrano & Pérez, 2011). For example, the use of wooden wastes from pallets on blocks for people to transit, may be an option. Wood composites haves some the advantage: do not corrode and are highly resistant to rot, decay, have less water absorption, present good mechanical stiffness and strength, have less environment effect, are often considered a sustainable material because they can be made using recycled plastics and the waste products of the wood industry (Jorge, Pereira & Ferreira, 2004).

Products that combine concrete-wood are called composites (Khorsandnia, Valipour & Crews, 2012). These products were developed after World War due to steel and concrete shortage (Khorsandnia et al., 2012) and have been used in the manufacture of construction materials for over 60 years (Tabarsa & Ashori, 2011, Ashori, Tabarsa and Sepahvand, 2012b). This kind of construction materials are manufactured by bonding wooden particles or fibers with cement or mortar mixture generating an attractive alternative for its use (Cheumani, Ndikontar, De Jéso & Sébe, 2011; Tittelein, Cloutier & Bissonnette, 2012).

Main advantages of these compounds have focused on its strength to decay and insect attack, acoustic properties and thermal insulation properties (Tabarsa & Ashori, 2011). Further on, these compounds have an opportunity for energetic rehabilitation of buildings and sustainable construction (Vergara, Vergara-González, Corral, Nájera & Otaño, 2013; Pinto, Fuentes, Fournely, Peña & Navarrete, 2015). Concrete reinforcement of wooden fibers, as indicates Taoukil, Sick, Mimet, Ezbakhe & Ajzoul (2013) may be a material that can be used in many applications such as formwork, floors, ceilings, screeds and interior masonry blocks.

Given these opportunities, this research aims to determine the feasibility of using wooden wastes from pallets in the manufacture of blocks, in order to obtain an environmentally sustainable product. Determining the proper mixed proportions cement-sand-stone powder and wooden particles, from pallets disposed after use. In each mixture analyzed, curing time by ultrasonic velocity, density variation during curing, resistance to accelerated decay, water absorption, module of rupture in flexion and abrasion resistance were determined. This information will allow developing a data sheet of the product with the technical specifications and evaluated parameters based on tests performed.

Material and methods

Selecting the shape of the block

The block used in this study was hexagonal (Figure 1). Its dimensions were 11.5 cm square and 8 cm thick, representing a volume of 2749 cm^3. This shape was selected to innovate in the market, since it is very unusual design to be marketed in Costa Rica.

Origin of the material used

The material used was obtained from the Employees Solidarity Association of MABE Industry (ASEMABE) located in Heredia, Costa Rica (9° 58' 35" N and 84° 6' 45" W). Wood was extracted from wasted pallets of *Pinus sp*, representing

a residue for the company. The wasted pallets were not utilized, and they deposited in municipal dump. Sand, stone powder and cement used come from trading companies that supply the Association in this location. Regarding cement type, it was used the general RTCR type UG-383:2004, in 50kg bags, produce by Holcim in Costa Rica (Holcim, 2018).

Raw material processing

Pallets were disarmed in individual pieces, removing all metal type components. Then, wood was chipped in a chipper machine NOGUEIRA model DPM-2, to get chips of approximately 3.5 cm long and 2 cm wide. Subsequently, chips were grinded in an own manufacturing grinder to obtain particles of smaller dimension to 8 mm in length. Sand and stone powder were used such as ASEMABE provided.

Treatments for the particles

Wooden particles were subjected to three treatment types: (i) Washing of particles, referred as T1, in this treatment, wooden particles were boiled in water (~100 °C) over one-hour period with constant stirring. Then, particles were washed with cold water until they were completely cold. Subsequently the particles were dried at room temperature for a period of one week and were subsequently place in a room with controlled conditions (Temperature of 22 °C and 66% relative humidity) until a 12% moisture content. (ii) Unwashed particles, referred as (T2), in this treatment the particles obtained from grinding process were used directly in the manufacturing of blocks. (iii) Treatment referred as T3 consists of adding calcium carbonate ($CaCO_3$) to the unwashed particles in an amount equivalent to 13% of its weight.

Formulation of mixtures

Regarding formulation of the mixtures, four types of mixtures were defined, which vary in the proportions of weight of the wooden particles according to each treatment used to manufacture the blocks (Table 1).

Characterization of the material used

Material was characterized using a sieving process. To performed this, 10 samples were taken from 95-105 grams, these were sieved in a column of sieves of 0.25, 0.425, 1.0, 1.7, 2.0, 3.35, 4.0, 6.7 and 8.0 mm, for a period from 2 to 3 minutes. After this time elapsed, material left in each of the sieves was weighted particle size distribution was defined by the weight of particles retained by sieve divided by the total weight of the sample used, expressed as a percentage. Regarding cement type, it was used the general RTCR type UG-383:2004. Fineness rate of the material was calculated by the sum of the accumulated amount of the material retained minus the percentage of material retained on the background divided by 100.

Table 1. Proportions by weight of materials used in each mixture according to treatments applied to the particles. Source: Self-Elaboration.

Mixture	Wooden particles		Total weight of block (kg)	Cement (%/Weight)	Sand (%/Weight)	Stone Powder (%/Weight)
	%/Weight	%/Volume				
Pattern	0	0	5.50	15.20	49.24	35.56
1	5.83	50	4.40	15.20	45.84	33.11
2	4.69	40	4.54	15.20	46.67	33.49
3	3.49	30	4.67	15.20	47.19	34.09
4	2.43	20	4.80	15.20	47.78	34.55

Manufacture of block sample

Blocks were manufactured with a density between 1500-2000 kg/m^3. Using the proportions established in Table 1, the amount was calculated, by weight, of the different elements composing the blocks (sand powder: cement: wooden particles). Subsequently, the amounts of each component was calculated to produce a total of 15 blocks per cycle. For this, materials were arranged in a mixer where water was added slowly to achieve an homogenous mixture. Then, the mixture was poured into two molds, and placed on a machine to apply a compression of 100 kg/cm^2 and vibration at the same time (Figure 1a). Blocks were covered with plastic after being manufactured, to avoid moisture loss. During

this period, blocks were moistened with water daily for eight days. This allows a good hydration for the cement used to manufacture the blocks and obtain a satisfactory hardening.

Properties evaluated in the blocks

Curing time. This property was determined through measurements of ultrasonic pulse velocity (UPV) in different day. UPV was calculated by measuring transmission from side to side, which represented the distance. Measurements were made every other day through 21 days in order to obtain the pattern of data regarding curing time. Measurements were carried out using ultrasonic equipment SYLVAESTDUO with 22 kHz transducers. In the configuration of this device it was set to make 4 readings per measurement. Transducers were placed on the center next to the measuring side at a distance of 20 cm one end to another. The ultrasonic velocity was calculated using Equation 1:

$$UPV = \left(\frac{L}{\frac{T}{1000}}\right) * 60 \qquad (1)$$

Where: UPV = ultrasonic velocity in Km * min^{-1}, L = length of the sample in meters, T = time that takes the ultrasonic wave from one end to another of the block in microseconds (μs).

Figure 1. Machine used to manufacture blocks (a) and shape of the block (b). Source: Self-Elaboration.

Density. Four samples were selected for each mixture for each treatment, which were weight any other day for 15 days. Volume of blocks was calculated according to its shape and height, corresponding to a volume of 2749 cm^3. Density of each block (kg/m^3), was calculated dividing its weight (kg) between its volume (m^3).

Water absorption. Water absorption of blocks was determined after 28 days since its manufacturing, following INTE 06-02-13 standard (INTECO, 2006) which is based on ASTM C140 standard.

Determination of the module of rupture of the concrete blocks. This property was determined 28 days after the blocks were manufactured, two blocks of each mixture were used for each treatment, which were left submerged in water for 24 hours before performing the test. The module of rupture of the block was determined using the INTE 06-02-14-06 standard (INTECO, 2006). The block was subjected to a load of weight, with a speed that produced an increase in the strength close to 0.5 MPa per second until the sample presents a failure (INTECO, 2006).

Abrasion resistance. To execute this test, two blocks from each mixture were used for each treatment and was performed with the INTE 06-02-15-07 standard (INTECO, 2006). Abrasion was determined using the abrasive wear measurement produced in the side facing the block, when subjected to abrasive friction through a wide metallic disc and sand, 28 days after its manufacturing.

Accelerated test of resistance to natural decay. To perform this test, three blocks from each mixture were used for each treatment. Then, from all blocks, 260 samples of 2 x 2 x 2 cm were extracted. The accelerated test of resistance to natural decay was carried out following the methodology of the standard ASTM designation D-2017-81 (ASTM, 2003).

Resistance degree to fungi attack was determined according to the classification proposed by ASTM (ASTM, 2003), considering class A (Highly resistance) when the average percentage in weight loss is between 0-10, class B (Resistance) with a percentage between 11-24, class C (Moderately resistance) with percentage between 25-44 and class D (slightly resistance to not resistance) with and average percentage of weight loss of 45 or more.

Statistical analysis

Particle size was classified calculating the percentages of retained material on each of the sieves used. For hardening velocity and density, regression models were determined adding equations and curves of best fit for data, to obtain the best determination coefficients (R^2). For results obtained from the test of moisture absorption, module of rupture and abrasion resistance, a t-student test ($\alpha=0.01$) was applied to different treatments and proportions. Results obtained from the accelerated test of resistance to natural decay, an analysis of variance (ANOVA) was applied to estimate the significance of the variation sources in data. The existence of significant differences between the averages for each variable was verified by the Tukey test (P<0.01).

Results

Characterization of the material used

The analysis of particle size distribution regarding weight, showed that wooden particles with dimensions between 6.7–4.0 and 3.35–2.0 mm represent the highest proportions, between 48–69% regarding weight (Figure 2a and 2b). For sand particles, dimensions between 3.35–2.0 and 1.0–0.425 mm, is where there is the largest amount of particles, representing 49% (Figure 2c). While for particles of sand and stone powder, between 12 and 20% have dimensions between 1.7 and 1.0 mm, and between 5 and 6% of the particles have smaller dimensions than 0.25 mm, unlike wooden particles that showed 8% and less than 1%, respectively in particles with these dimensions (Figure 2).

Figure 2. Size distribution of the wooden particles (a), stone powder particles (b), and sand particles (c) in percentage, regarding weight used in the manufacturing of the blocks. Source: Self-Elaboration.

Particle size (mm): ■ >8 ■ 8 - 6.7 ■ 6.7 - 4 ■ 4 - 3.35 ■ 3.35 - 2 ■ 2 - 1.7 ■ 1.7 - 1 ■ 1 - 0.425 ■ 0.425 - 0.25 ■ < 0.25
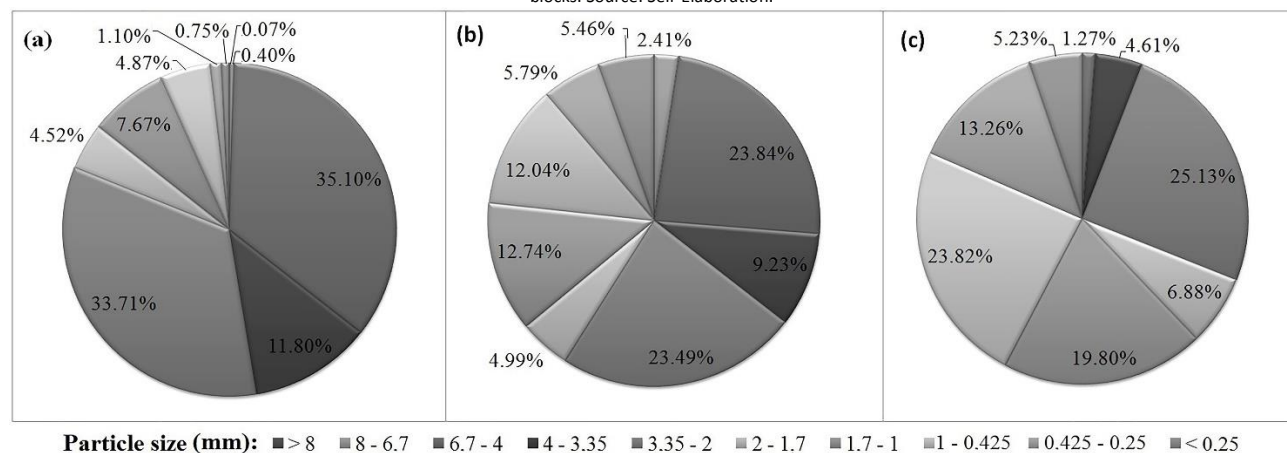
Curing time. This parameter for the different mixtures, measured by USV, is shown in Figure 3. We can observe that blocks manufactured without wooden particles is where most USV occurs. Also, we can observe that regardless the type of mixture and /or treatment of the particles, USV has a growth from the manufacture until the 9th day approximately and after this day, USV starts to remain constant.

Density. Variation on density of different mixtures is shown in Figure 4. We can observe that blocks manufactured without wooden particles are those with the highest density. Likewise, it is observed that density value in all mixtures is decreasing over time, however, the variation from a measurement to another is very little, therefore, we can appreciate an almost constant pattern.

Figure 3. Ultrasonic pulse velocity (USV) variation with time for four mixtures with different proportions based on three treatments applied. Source: Self-Elaboration.
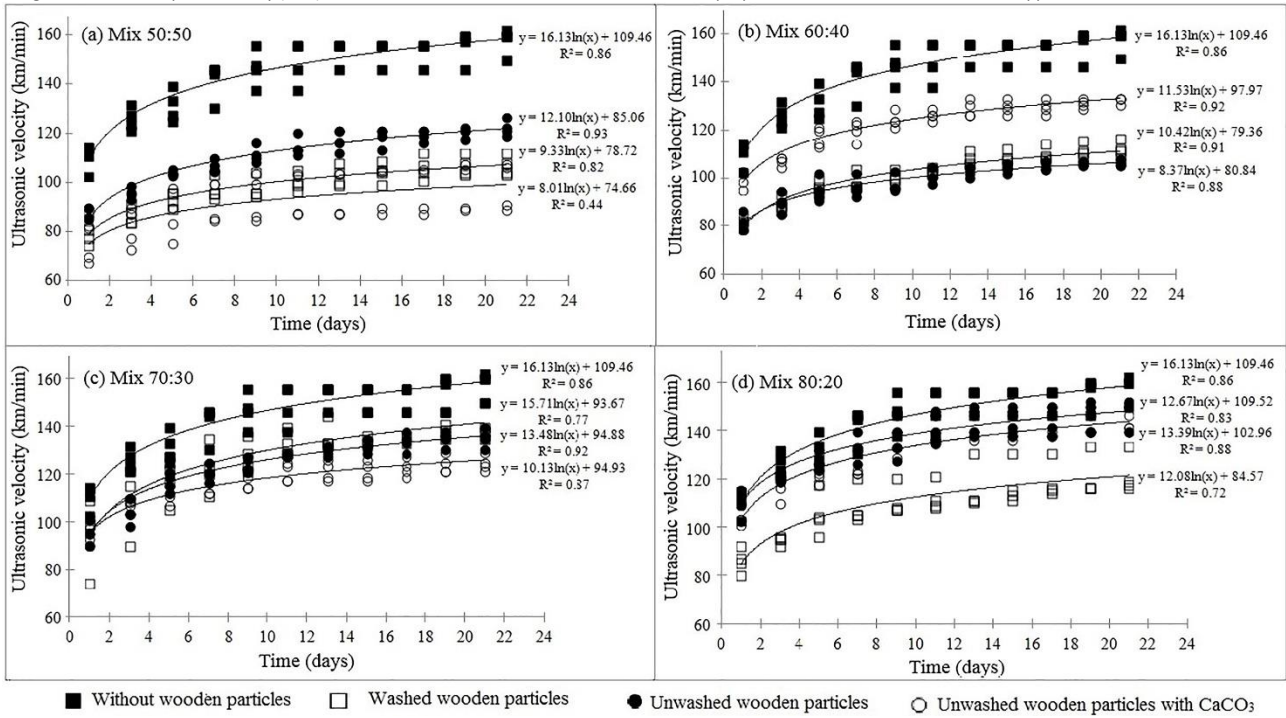
When interpreting each of the proportions across of 15 days after fabricated (Figure 4) and in the ending of 15 days (Table 2), in the 50:50 mixture is observed that when blocks are manufactured with unwashed particles, show a higher density compared to blocks made from washed particles and unwashed particles with $CaCO_3$, which at the same time have very similar density values at different measurement days (Figure 4, Table 2). For the 60:40 mixture, we can observed that blocks manufactured with unwashed wooden particles and $CaCO_3$, have higher density values compared to blocks manufactured with washed and unwashed wooden particles, showing density values similar to each other (Figure 4b, Table 2). Moreover, in the 70:30 mixture was observed that blocks made from washed wooden particles, unwashed and unwashed with $CaCO_3$, have very similar density values at different measurement days. However, we may notice that blocks manufactured with unwashed wooden particles are showing the lowest density values (Figure 4c, Table 2). As for 80:20 mixture, we can notice that both blocks made with washed wooden particles unwashed and unwashed with $CaCO_3$, showed very similar density values with each other at different measurement days. Although, we can appreciate that blocks made with washed particles are showing the lowest density values (Figure 4d, Table 2).

Figure 4. Density variation with time for four mixtures with different proportions based on three treatments applied. Source: Self-Elaboration.
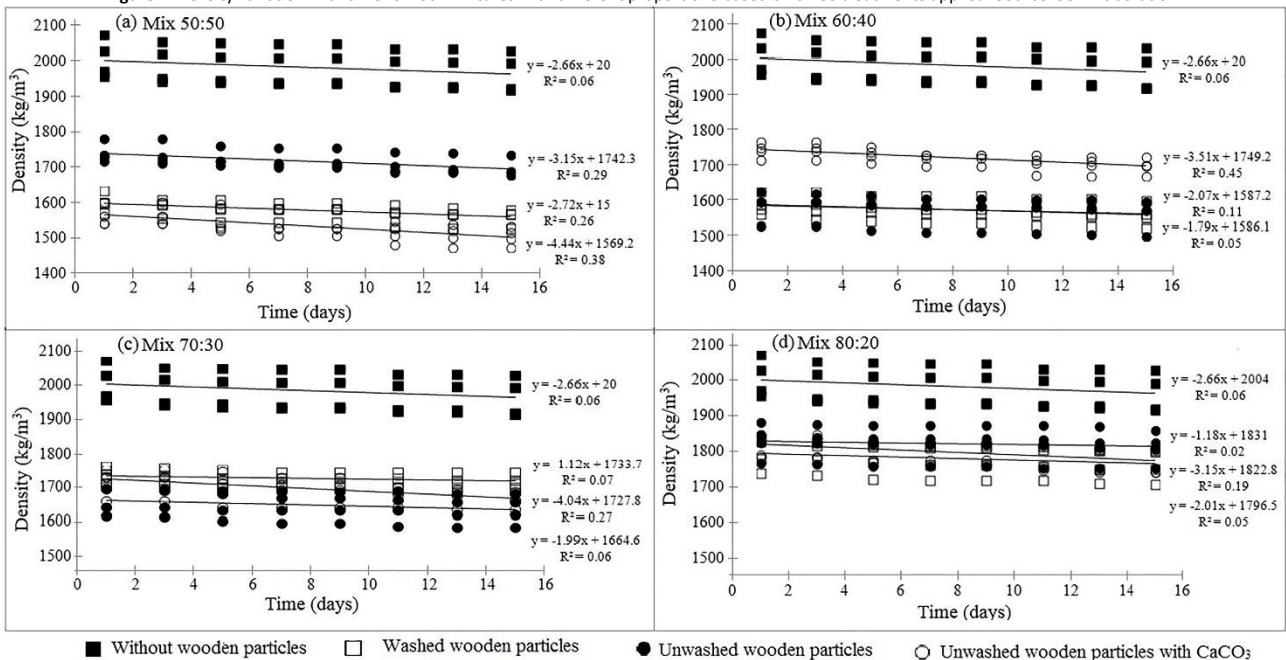
Water absorption, module of rupture in flexion and abrasion resistance. In the moisture absorption test (Figure 5a), it was found that the value decreases by decreasing the amount of wooden particles in the blocks or by increasing the proportion of sand and stone powder. We may also notice that the mixture with proportions 60:40 in the blocks manufactured with unwashed particles with $CaCO_3$, have significant difference (for $\alpha=0.01$) with the other treatments (washed particles and unwashed). For the rest of the mixtures there is no significant difference between treatments or mixtures. In the module of rupture (Figure 5b), the pattern is irregular in the different mixtures. Blocks made with unwashed wooden particles and $CaCO_3$, have a significant difference in mixtures with proportions 50:50, 60:40 and 80:20, for $\alpha=0.01$ (Figure 4b). As for the other mixtures no statistically differences were obtained, except with the 80:20 mixture (Figure 5b).

In the abrasion resistance test (Figure 5c), also has a very irregular pattern between mixtures. Blocks manufactured with unwashed particles, have little difference between the mixtures, but at the same time show the lowest wear values for mixtures with proportions of 60:40 and 70:30 determined by the track length. By contrast, blocks made with washed particles, were those with the greatest wear values for mixtures with proportions 50:50, 70:30 and 80:20 (Figure 5c).

Figure 5. Patterns in the moisture absorption test (a), module of rupture test (b) and abrasion resistance test (c) for the different mixtures in different proportions based on the treatments applied to the particle. Source: Self-Elaboration.
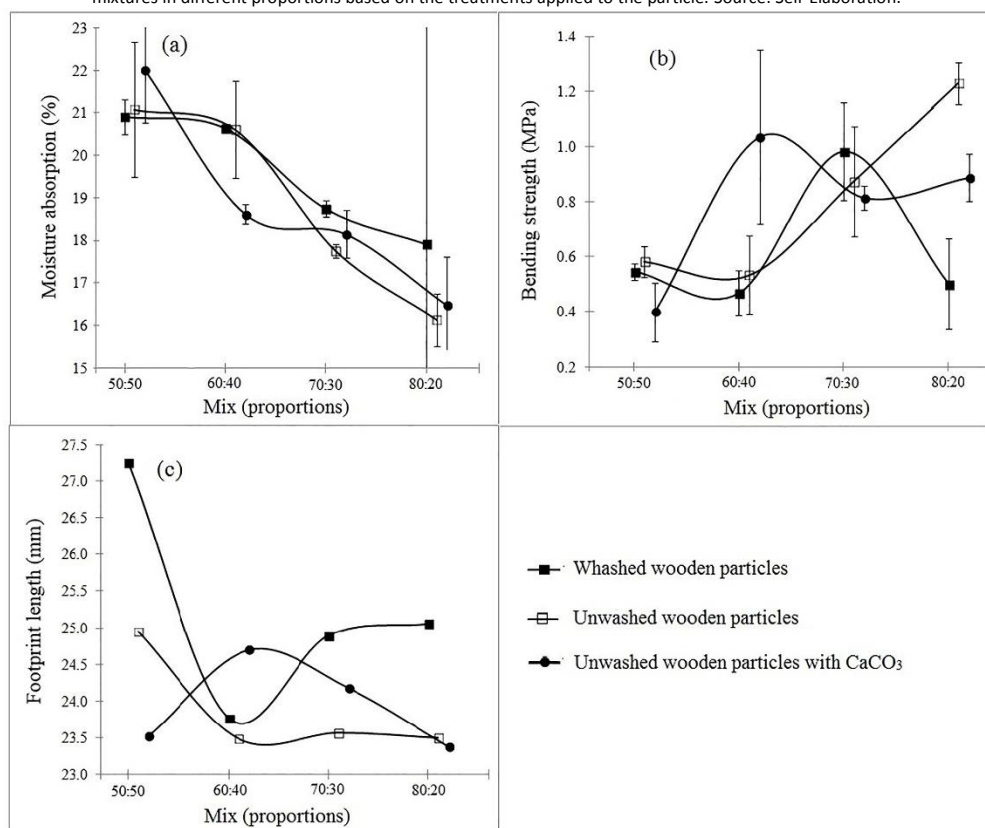
Accelerated test of resistance to natural decay: In the accelerated test of resistance to fungi attack (Table 2) it was found that there is no significant difference ($\alpha=0.01$) between the different mixtures and treatments of the particles. An important aspect to note, is that weight losses were negative. Likewise, it was observed a large variability in the values of the variation coefficients (CV).

<div align="right">Discussion</div>

Characterization of the material used

The materials used in the manufacture of blocks mostly have smaller dimensions to 8 mm (Figure 2), which are suitable for this type of product. Particles size affects the mechanical properties of the compounds, besides the process conditions and cement-wood ratio used (Nazerian & Sadeghiipanah, 2013). For example, the use of particles with small dimension causes curing inhibition rates of greater magnitude compared to those made with larger dimension particles,

therefore, this particle size is suitable to the type of product. Having plant particles with an elongated geometry in the manufacture of wood-cement compounds, allows for greater product stability (Beraldo & Balzam, 2009).

Table 2. Average percentage of weight loss of the blocks under decay test for 16 weeks based on two types of fungi. Source: Self-Elaboration.

Treatment	Mixture	Density at 15 days after fabricated	*Trametes versicolor*	*Lenzites acuta*
Pattern	100:0	1965 (2.84) A	-1,41 (13.25) A	-1.57 (16.44) A
Wooden particles washed (T1)	50:50	1561 (1.44) B	-0.78 (102.59) A	-1.70 (51.30) A
	60:40	1557(2.03) B	-1.59 (19.04) A	-1.71 (36.73) A
	70:30	1720 (1.15) C	-1.63 (16.51) A	-1.80 (34.76) A
	80:20	1767 (2.53) D	-1.69 (22.40) A	-1.66 (37.32) A
Wooden particles unwashed (T2)	50:50	1696 (1.56) B	-1.31 (28.22) A	-1.28 (49.64) A
	60:40	1559 (2.65) C	-1.56 (10.23) A	-2.13 (15.66) A
	70:30	1637 (2.54) B	-1.81 (9.32) A	-1.73 (35.52) A
	80:20	1812 (2.44) D	-1.76 (16.03) A	-2.30 (22.38) A
Wooden particles unwashed with CaCO$_3$ (T3)	50:50	1505 (1.67) B	-1.34 (20.65) A	-1.69 (39.48) A
	60:40	1699 (1.32) C	-1.13 (36.14) A	-1.95 (32.06) A
	70:30	1669 (1.39) C	-1.46 (4.70) A	-1.67 (34.53) A
	80:20	1776 (2.19) D	-1.78 (14.46) A	-2.03 (14.25) A

Legend: The value in parenthesis indicates the variation coefficient of 10 samples. Values with similar letters indicate there is no significant statistical difference at 99% confidence.

Curing time and density

Increasing the UPV in time, mainly from day zero to the ninth day (Figure 3), is normal for this type of product. Most significant changes in UPV are obtained during the first weeks of being manufactured; then, values begin to stabilize (Beraldo & Balzam, 2009). This increase is due to the curing process and the hardening of cement (Beraldo & Martins, 2007).

Moreover, Beraldo & Martins (2007), state that to a higher content of wooden particles, decreases the UPV, this because there is greater discontinuity in the composition of the structure, preventing a proper propagation of waves. What is possible to test in this study, since blocks manufactured with washed particles, unwashed and unwashed with CaCO$_3$ in the 50:50 mixture is that has the lowest UPV values (Figure 3a) compared to those found for the same treatments but with proportions 80:20, that had higher UPV values (Figure 3d).

High values for UPV, ranging between 90 and 120 km/min, are a good indicator of the compatibility degree between wood and cement (Beraldo & Balzam, 2009). In this study, it was found that the average values of UPV obtained on the last day of measurement for the mixtures in all treatments applied (Figure 3), exceed the minimum value of the range indicated above, so there is a good compatibility between cement and particles of *Pinus sp* used for this study. Likewise, in order to improve UPV values to near or above 120 km/min, it is necessary to add accelerators or additives, such as calcium chloride (CaCl$_2$), to the wooden particles to promote hardening of the mixture (21), as was again tested in this study.

Regarding density values found in this study, from 1473 to 2073 kg/m^3 (Figure 4), it is found that are higher than density values reported by Karade (2010), who indicates density values between 920–1250 kg/m^3 for concrete products made from wastes of wood from constructions in Japan. The other worth noting aspect, is the decrease in density with time (Figure 4). This pattern occurs due to weight loss of the blocks caused by the evaporation of moisture during the drying process (26). Also, a decrease in density is evidenced when the amount of particles increases, as established by Torkaman et al. (2014). For example, blocks manufactured with unwashed particles with CaCO$_3$ for the mixture with proportions 50:50 has an average density (1505 kg/m^3) lower than blocks made with proportions 60:40 (average density

of 1699 Kg/m^3). Decrease in density in high proportions is due to the substitution of sand and stone powder by wooden particles, which are of lower density (Leng, Al-Qadi & Lahouar, 2011).

Water absorption, module of rupture in flexion and wear

Moisture absorption increases as the amount of wooden particles in the block increases (Figure 5a). This pattern is explained by the fact that wood will represent empty spaces and it is a hygroscopic material which allows it to absorb or release water depending on the conditions it is found (De Roma, 2001). However, moisture absorption can be controlled by impregnating the cell wall of lignocellulosic materials with water-soluble polymers (Karade, 2010; Stancato, Burke & Beraldo, 2005). In Figure (5a), we can appreciate that, by adding CaCO$_3$ to the wooden particles only in the mixture with proportions 60:40, it was possible to obtain a decrease in the moisture absorption percentage compared to other treatments, therefore, it can be inferred that in this study, adding CaCO$_3$ to the wooden particles does not represents a decrease in water absorption in the block.

For the module of rupture, results obtained have an irregular pattern, but it demonstrates a slight decrease when wooden particles amount increases (Figure 5b). The mixture that most evidence a decrease in density in relation to the proportion of wood used were those blocks manufactured with unwashed particles. This decrease is attributed to a reduction in the flexural strength of the final product, due to the presence of extractives in fibers (Nazerian & Sadeghiipanah, 2013), which can interfere with the hydration process of the cement (Viera & Ayala, 2006).

Adding CaCO$_3$ to the mixtures and the washed particles improve the module of rupture (Figure 5b), as it occurs when adding other additives to increase cement hydration (Karade, 2010). These mineral components can penetrate the cell wall of wooden particles, leading to improve the adhesive forces between wood and cement (Nazerian & Sadeghiipanah, 2013). Although, not in all cases occurs, for example, blocks made with unwashed particles and CaCO$_3$ regarding blocks made with washed particles and unwashed this is not true, especially for mixtures with proportions 50:50, 70:30 and 80:20 (Figure 5b). In these case, these variations happen because this type of additive is not suitable for the mixture, because some properties was not improvement. Probably, the additive he penetration of particles were not effectives for hydration to cement (Karade, 2010) or the extractives of wood affected the relationship additive-cement (Nazerian & Sadeghiipanah, 2013).

Finally, results obtained from the abrasion resistance are also very irregular, fluctuating between 21.22 mm and 27.25 mm footprint length (Figure 5c). However, mixtures with proportions 60:40 and 70:30 for blocks manufactured with unwashed wooden particles, have the lowest values for track length, with values of 23.49 mm and 23.57 mm respectively, indicating a greater resistance to wear (Figure 5c). According to the standard INTE 06-02-15-07, INTECO (2006), is acceptable when there are values for track length in a range of 19-24 mm, Moreover, results outside this range are rejected, since track length values above 24 mm indicate that the block wears very easily and values less than 19 mm indicate that the block is too rigid. Consistent with the results obtained and ranges established by the norm, we have that blocks made with unwashed wooden particles are those with greater acceptance for all mixes, except for the mixture with proportions of 50:50, this compared to the other treatments. Although, to improve wear resistance is necessary to increase the hardening or the age of the block (Siddique & Khatib, 2010).

Accelerated test of resistance to natural decay

In the accelerated test of resistance fungi attack, negative values obtained (Table 2), showed that samples gain weight, therefore, the compounds do not exhibit significant fungi attack, so it is classified as "highly resistance" to fungus *Trametes versicolor* and *Lenzites acuta* according to ASTM 2017 standard (ASTM, 2003). This result is consistent with Okino, de Souza, Santana, Alves, de Sousa & Teixeira (2004; 2005), who indicate that in compounds of wood-cement there is no measurable degradation of wood (weight loss) and the mycelium does not cover the surface of the samples completely. Moreover, Papadopoulos (2008), reports that fungi fail to attack the compound of cement with Maple particles bonded, and found a weight increase of 5% in mass, as the present study. This author justified the increase of weight in the compound to a carbonation of cement (Papadopoulos, 2008). Consistent with the results in this study and those reported by Okino et al. (2004; 2005) and Papadopoulos (2008), indicated that these compounds are technically suitable for outdoor use, where both moisture and favorable conditions are present for the development of fungi.

Conclusions

The evaluation of density variation and ultrasonic velocity showed a variation from 1473 to 2073 kg/m^3 and from 98 to 158 km/min, respectively. Compounds with wooden particles unwashed and unwashed with CaCO$_3$, have the best

results for density and hardening, with very similar values with each other. Moisture absorption and module of rupture test, showed a variation of 15 to 20% and from 0.40 to 1.23 MPa, respectively. Blocks made with unwashed wooden particles (T2) and unwashed with $CaCO_3$ (T3) are those with the best results. In the abrasion test, it showed a variation in the footprint length between 21.22 to 27.25 mm. The accelerated test of resistance to natural decay, showed that samples increase the weight with both fungus types, indicating a degree of resistance of these fungi classified as "highly resistance" to all mixtures and treatments evaluated. Results indicate that the mixture with proportions 60:40 for blocks with unwashed wooden particles and $CaCO_3$ (T3), is one that has good performance in all parameters evaluated.

Finally, there is necessity for further researches regarding appropriate pre-treatment methods, proportioning of and compatibility between the *Pinus sp* waste in the different mixing ratios coupled with the production of blocks with acceptable properties using cement inclusion in order to reutilize the pallet waste, in order to contribute to efforts at alleviating poverty in this part of the world in line with the objectives of the reutilization.

Acknowledgement

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