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Assessment of cement-based boards reinforced with fibers extracted from Andean Ichu grass

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ABSTRACT

The continuous growing of the construction industry it is challenging to find the right choice for raw materials especially fibers for cement-based composites. In this study, raw Ichu fibers were evaluated to be used as reinforcement of cement matrices; mercerization treatment of the original fibers followed by the shear defibrillation technique were used to obtain the pulp; afterward, slurry-dewatering with the final pressing process technique were used to manufacture the composites boards. Results show that Ichu fibers required low aggressive mercerization treatment; furthermore, with mechanical shear defibrillation more than 80% of the defibrillated fiber present an aspect ratio over 80. The manufactured fiber cement composites board present a modulus of rupture over 8 MPa; moreover, with outdoor and indoor aging, samples modulus of rupture increases, reaching around 13.5 MPa for the outdoor aging; furthermore, progressive embrittlement was observed with impact over aging time. Finally, based on the mechanical properties of the boards, results suggest that with 9%wt of the Ichu pulp fibers as reinforcement, boards shown a bests characteristic.

Keywords: Ichu fibers; fiber cement composites; natural fibers; mechanical properties; physical properties.

1. INTRODUCTION

Since recent years fiber cement boards have been commonly used in various non-structural applications such as internal walls, external walls, roof covering and cladding (Khorami, 2019). Its composition is based mainly on a matrix of Portland cement and fibers as reinforcement, which produce a substantial increment in the mechanical properties of the final composites, such as its flexural strength, fatigue, impact, toughness and permeability. The most widely method used for the production of these boards is the Hatschek process (slurry-dewatering), which allows the manufacture boards in different thicknesses and shapes depending on their application. According to Reichert, approximately 85% of the fiber cement products sold in worldwide are the product produces by the Hatschek method (Ikai et al., 2020). Nonetheless, the methodology and composition of fiber cement has undergone changes over time, due to the incorporation of new chemical and mineral additives, different fiber options and matrixes with different characteristics (Bezerra et al., 2016).

Last decades, polypropylene (PP) and polyvinyl alcohol (PVA) fibers have been the most used as reinforcement in the production of fibrocement; however, due to its synthetic nature, the production of this type of fiber requires a large amount of energy, as well as chemical and petrochemical raw materials, causing damage to health and the environment in the long run (Tonoli, 2019). Because of that, great interest has been focused in the use of lignocellulose fibers as a replacement for synthetic reinforcements. Fibers such as corn stalks, sunflower stalks, eucalyptus, sisal, bamboo, flax, banana, jute, bagasse, kraft and so on (Khorami, 2019, Jarabo, 2013, Fuente, 2020) were explored. Lignocellulose fibers present excellent properties such as low density, low cost and it is environmentally friendly material (Yang et al., 2019). Even though these benefits, fibers are not compatible with mineral matrix like cement, due to tannin, sugar, starch, phenols, hydroxylated carboxylic acid compounds present into the lignocellulosic fibers (Santos et al., 2017); because of that, they should be treated prior to use as a reinforcement. The most widely method used to treat these fibers is the mercerization (alkali treatment), which can be done using NaOH solution; KOH and Ca $(OH)_2$ can be used as well (Azevedo et al., 2022). With the mercerization, outer surface extractives can be removed, lignin and hemicellulos as well (Santos et al., 2017); as a consequence, cellulose proportion into fiber increases and with this, their mechanical properties; furthermore, fiber compatibility with the matrix can be improved and fiber dimensional stabilization as well.

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Literature suggest that the fibers in the range of 8 – 12% wt%, from the overall fiber cement composite, are the optimal proportion of the reinforcements to obtain the maximum performance in the mechanical properties (Coutts, 2011). Furthermore, lignocellulose fibers are good enough reinforcement to compete with the synthetic fibers, especially to reinforce mineral matrixes like cement (Shahinur and Hasan, 2020). However, its shape (aspect ratio) and its chemical composition are key parameters to exploit its maximum capacities in composites. When the natural fibers were used without treatment, the properties of fiber cement composites will not exceed 3 MPa (Hasan et al., 2021); on the other hand, according to Savastano et al., the mechanical properties of the fiber cement composites using the sisal pulp fibers, can reach over 18 MPa in the modulus of rupture (Savastano et al., 2016). The pulping process itself is a surface modification process, and this process can give the fibers dimensional stability, thus improving the properties of the final fiber cement composites and their durability (Fuente et al., 2020).

Another aspect to be considered in the production of fiber cement composite is the energy spent to produce the cement matrices, it is known that the limestone can replace up to 15% wt the cement matrices into the fiber cement composites (Gudissa, 2010, Mohammed, 2010). Ichu fibers (Stipa obtusa) or commonly called in Peru as “paja brava” is a grass of the Andean area. Since ancient times, this grass had been widely used by local people as a building material for roofs and for weaving ropes. Nevertheless, the introduction of new construction materials has significantly diminished their usage (Mori et al., 2020). Different properties of the Ichu fibers have been studied during the last years, the findings of these studies indicate encouraging outcomes (Mori, 2020, Candiotti, 2020). An additional benefit of these materials is their accessibility and affordable harvesting cost (approximately $0.15/kg). Research utilizing image segmentation techniques estimates a potential annual production of over 70,000 tons of these grasses across the Andean region (Mori et al., 2020). Since the Ichu fibers are novel materials, their treatment and their properties were explored using a design of experiment (DOE) methodology, showing excellent mechanical properties as single material and in composites (Mori et al., 2020). These characteristic gives to these fibers high potential to be explored in another application like fiber cement composites.

The main objective of this research is to determine the feasibility to use Ichu grass fiber as a reinforcement of cement matrices; manufactured panels were evaluated after fully cured and after natural weathering (indoor and outdoor); physical and mechanical properties is going to be presented and analyzed.

2. MATERIALS AND METHODS

2.1 Reinforcement

Since raw fibers show high proportion of extractives in their composition, prior to manufacture the pulp, they were subjected to mercerization process (0.5 M, NAOH at 60°C, for 4 h); with this process, part of the lignin, waxes and other extractives were removed, Table 1 shows the true density and chemical composition for the raw and treated fibers (Charca et al., 2015). From the bundle of treated fibers (mercerized), uniform shape fibers where selected in order to measure their mechanical properties, according to the ASTM C1557-14 and Candiotti recommendation (Candiotti et al., 2020); the test was performed using displacement control with 1.2 mm/min and gauge length of 20 mm. On the other hand, remaining treated fibers were manually cut to lengths between 10 - 20 mm, after that; 30 g. of fibers were pulp by mechanical shearing technique in 1 L of water for 3 minutes using blender, each minute the speed was changed, from 3400 rpm, then to a speed of 7600 rpm and finally, to a speed of 17500 rpm (the blender used for this process was Oster Xpert). This blended product was drained in a strainer, in order to eliminate as much water as possible; then it was placed to dry in the oven at 60°C for 48 h. It is important to mention that the true density and chemical composition of the pulp fibers, shown in the Table 1, were measured immediately after the mercerization process, since the pulping process is purely mechanical, the chemical composition and the true density should not change after the pulping process.

Once the pulp fibers are ready, certain number of fibers were taking randomly and placed in a petri with small amount of water and in the top of that, transparent glass was placed; with this setup and with the microscope (Olympus SZ), thickness and length of each fiber filament can be measured.

Tabla 1. True density and chemical composition of fibers used as reinforcement according to the TAPPI standard (Tenazoa et al., 2021)

	Raw Ichu fibers (wt%)	Treated Ichu fiber (pulp fibers, wt%)
Density (gr/cm^3)	1.34 ± 0.03	1.51 ± 0.02
Cellulose	69.37 ± 0.79	90.75 ± 0.32
Hemicellulose	2.63 ± 1.63	0.41 ±0.92
Lignin	12.13 ± 0.29	4.15 ± 0.3
Extractives	10.49 ± 0.00.36	3.43 ± 0.27
Ashes	5.05 ± 0.00.41	1.23 ± 0.23

2.2 Matrices

Cement, Sol UNACEM - Portland Type I (NTP-334.009) cement was used as main matrix, their composition is showing in the Table 2. This type of cement was chosen because it does not present major mineral additions in its composition.

Limestone, this material was used as a partial replacement for Portland cement (COMACSA), their composition is showing in the Table 2.

Table 1. Cement and limestone composition (% weight, Sol UNACEM - Portland Type I and COMACSA)

	CaO	SO_3	MgO	SiO_2	Al_2O_3	C_2S	C_3S	C_3A	C_4AF
Cement	-	3.00	2.93	-	-	11.9	54.2	10.1	9.7
Limestone	46 - 52	Max 1.0	0.75 - 1.5	10 - 16.5	1.9 - 3.5	-	-	-	-

2.3 Fiber cement board manufacturing

Boards were manufactured using three pulp fiber weight fractions (6, 9 and 12 %wt); as a matrix, 12%wt of limestone and the rest Type I Portland cement were used. The technique used was slurry-dewatering with the final pressing process, which can be summarize as follow; the corresponding fiber pulp was placed in a 1600 mL water container and stirring at 1000 rpm for 5 min; after this time, the cement and the corresponding limestone were added according to the compositions. This mixture was stirred for 10 more minutes at the same speed, to then be poured into the mold, after that a vacuum (-60 kPa) was applied for 5 minutes in order to remove water. Afterward, manufactured board was removed from the vacuum chamber and taken to the hydraulic press where a pressure of ~ 2.8 MPa was applied for 5 minutes to obtain the final thickness of ~ 6 mm. The final board was removed from the press and placed in hermetic bags for 48 hours at room temperature. After that, the boards were cured by being immersed in water for 26 days. Once the curing process was finished, the panels were cut into the specimen sizes for flexural tests and impact test, using a diamond disk cutter cooled by water.

2.4 Natural weathering

A group of samples were exposed to natural weathering for a period of 6 and 12 months, considering two aging conditions: a) laboratory environment, the samples were placed with a 45º of slope with a light intensity of 0.001 to 10 Lux, relative humidity of 75 to 95%, with a temperature of 16 to 22°C; b) Outdoor environment, the samples were installed in a sample rack with an slope of 30º oriented to the north (south hemisphere), on the roof of the Universidad de Ingenieria y Tecnologia (latitude 12º 6 '6.98 ”, longitude 77º 1' 20.91”), altitude 200 masl, ambient temperature from 11 to 27°C, relative humidity from 65 to 95%, maximum wind speed 11 m/s and average 3.11 m/s, total rain precipitation of 11.2 mm during the period of aging, maximum solar radiation of 1148.00 W/m^2 and 0.8 km m away from the Pacific Ocean.

2.5 Physical Properties

Physical properties like bulk density (apparent density), water absorption, and apparent porosity of the samples were determined according to the ASTM C948 Standard test methods. For the measurement of the thickness swelling (TS), samples were completely immersed horizontally under water maintained at 25ºC for 24 h; after soaking, samples were drained on paper towels to remove excess water; thereafter, thickness at different specific points were measured in each sample using a micrometer, afterward, samples were dried in an oven at 60°C for a week; after that, the drying temperature in the oven was increased to 100°C and the weight of the samples was measured periodically until reaching a same previous measure; finally, thickness was measured at the same location were measured previously.

2.6 Mechanical Properties

Tests were performed using MTS Exceed with 5 kN of load cell under displacement control (1.5 mm/min). Three-point bend test method with 120 mm of span was used to determine, the stress at the limit of proportionality (LOP, Eq. 1), elastic modulus (MOE, Eq. 2), modulus of rupture (MOR, Eq. 3), and the toughness of the material (Eq. 4).

$$\text{LOP} = \frac{P_{lop}.L}{b.h^2} \tag{1}$$

$$\text{MOE} = \frac{276.L^3}{1296.b.h^3}.m^3 \tag{2}$$

$$\text{MOR} = \frac{P_{max}.L}{.b\ h^2} \tag{3}$$

$$\text{Toughness} = \frac{absorbed\ energy}{b.h} \tag{4}$$

Where Plop is the load corresponding to the upper point of the linear portion of the load deflection curve, L is the span length between supports, b and h are the samples width and thickness, m is the slope of the linear portion of the load-deflection curve and Pmax is the maximum load reach during the test. The absorbed energy is the area under load-deflection curve up to the point corresponding to 0.3 of MOR.

Impact strength was also measured using 10 mm x 7 mm x 100 mm unnotched samples. This test was performed using Gunt Pendulum Impact Tester 25 Nm; since impact strength is considerable low for this kind of material, the minimum scale was rescaling in order to obtain a reasonable measurement. For the flexural test and impact test, 7 samples were tested as a minimum.

3. RESULTS AND DISCUSION

3.1 Pulp fibers characteristics

Treated Ichu fibers (mercerized) have a linear elastic behavior as shows Figure 1, similar curves were found in the previous studies (Mori, 2020, Tenazoa, 2021); however, stiffness, strength and strain to failure have higher values compared to the reported; these higher values are related to the higher cellulose content. Figure 2, shows the Weibull plot for the modulus of elasticity, strength and strain to failure for the treated fibers, shape parameters are over 6, which mean that the results have consistent value; similarly, R has values over 0.92.

Treated fibers were subjected to the mechanical shearing defibrillation process, the resultant pulp fibers aspect ratio was determined; Figure 3 shows the aspect ratio distribution histogram and the Weibull plots. It is clear that after the mechanical pulping, more than 70 % of the fibers present an aspect ratio over 80, which are optimum to be used as reinforcement; however, around 30 % of the defibrillated fibers can be classified as fine particles; due to the short length, these fibers cannot have a direct effect as a reinforcement. The average value of the aspect ratio was 62.96 with average fiber thickness of 12.31 μm.

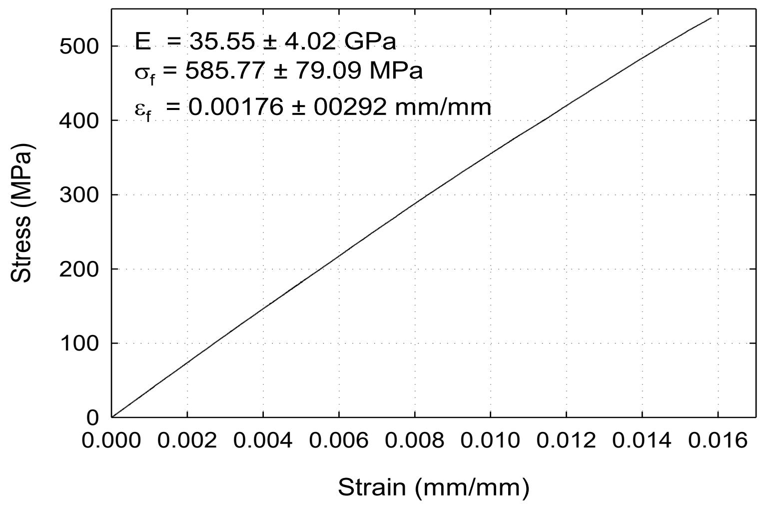

Figure 1. Typical stress - strain curve for the treated Ichu fibers

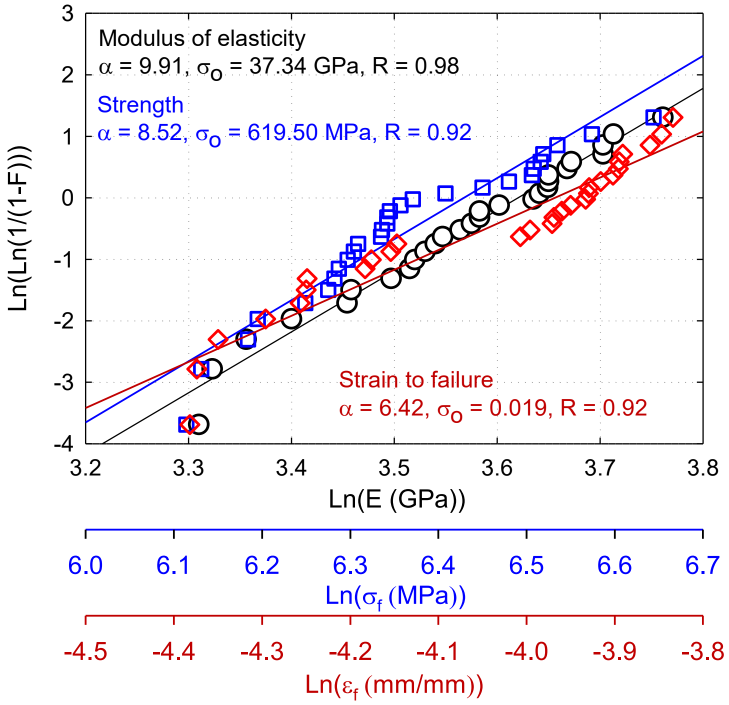

Figure 2. Weibull distribution plot for the modulus of elasticity, strength and strain to failure for the treated fibers

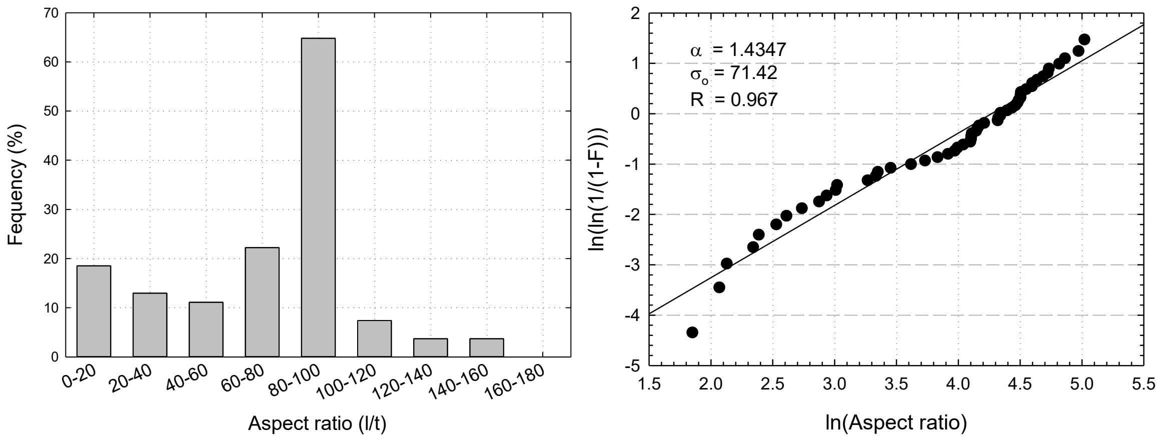

Figure 3. Pulp fiber characteristics, a) aspect ratio histogram, b) Weibull distribution plot of aspect ratio.

Aspect ratio plays an important rule to increase the effectiveness to transfer the load from the matrix to the fiber, and with this the improvement of the strength and the toughness of the composites. Studies developed on bamboo, eucalyptus and pine pulps reinforcing cement matrices shows similar average aspect ratio (51, 61 and 53 respectively) (Mori, 2020, Correia, 2018); although, it would always be better to have larger aspect ratios to improve mechanical interlocking.

An important aspect on the natural fibers is the lignin content, since the lignin is highly susceptible to degradation in alkaline environment. The studied Ichu fibers has considerably lower percentage of lignin (< 5%, Table 1), compared to reported in previous studies (Charca, 2015, Tenazoa, 2021); these differences are commonly observed in biomass materials, since depends on the plants growing condition.

3.2 Physical properties of fiber cement composites: apparent density, water absorption, apparent porosity and swelling

Table 3 and Table 3 show the physical properties of the fiber cement composites, considering the weight percentage of the fiber and the aging time in two environment conditions. Results for the unaged samples shows that, with greater amount of fiber the apparent density, water absorption, apparent porosity and swelling increases. On the other hand, apparent density increases with aging time as well as the water absorption, apparent porosity and thickness variation (swelling); however, after 6 months, their values maintain relative constant, even decreases.

Table 2. Apparent density and percentage of water absorption for samples aged in laboratory (indoor) and outdoor environment.

Time (month)	Apparent density (g/cm3)						Water absorption (WA, %)					
	6 %wt		9 %wt		12 %wt		6 %wt		9 %wt		12 %wt	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
0*	1.40 ± 0.031		1.45 ± 0.020		1.49 ± 0.016		11.9 ± 1.080		12.6 ± 0.230		13.8 ± 0.870	
6	1.84 ± 0.05	1.91 ± 0.04	1.79 ± 0.07	1.90 ± 0.05	1.70 ± 0.08	1.78 ± 0.13	20.7 ± 0.78	18.3 ± 0.74	22.3 ± 0.95	19.2 ± 0.88	26.2 ± 2.69	24.0 ± 2.01
12	1.76 ± 0.04	1.83 ± 0.02	1.71 ± 0.09	1.85 ± 0.03	1.63 ± 0.09	1.69 ± 0.11	20.9 ± 0.70	18.7 ± 0.76	23.0 ± 1.38	18.7 ± 0.56	25.9 ± 2.06	24.5 ± 2.21

0* correspond to samples cured 48 h in a sealed bag + 27 days in water.

Table 3. Apparent porosity and percentage of thickness variation (swelling) for samples aged in laboratory (indoor) and outdoor environment.

Time (month)	Apparent porosity (%)						Swelling (%)					
	6 %wt		9 %wt		12 %wt		6 %wt		9 %wt		12 %wt	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
0*	18.5 ± 1.410		19.31 ± 0.32		20.9 ± 1.010		0.14 ± 0.012		0.37 ± 0.016		0.51 ± 0.097	
6	27.6 ± 0.56	26.1 ± 0.60	28.6 ± 0.57	26.8 ± 0.55	30.7 ± 1.53	30.0 ± 0.72	1.08 ± 0.57	1.00 ± 0.20	1.03 ± 0.35	1.53 ± 0.37	0.77 ± 0.09	1.84 ± 0.33
12	27.1 ± 0.25	25.5 ± 0.68	28.3 ± 0.89	25.8 ± 0.33	29.6 ± 0.79	29.3 ± 0.80	1.27 ± 0.21	1.33 ± 0.09	1.60 ± 0.15	1.45 ± 0.24	1.80 ± 0.46	1.42 ± 0.25

0* correspond to samples cured 48 h in a sealed bag + 27 days in water.

According to the results, samples with outdoor aging present in overall higher density for all weight ratios, compared to the indoor aged; the increment in the density over time was observed by Akers, 1989, as well. Furthermore, studies developed in roofing tiles reinforced by vegetable fibers (< 6 %wt) shows that their density increases after 155 days exposed to natural weathering aging; although, their values do not exceed 1.4 g/cm^3 (Roma et al., 2018). Tonoli 2007, attributed that the increment in the density is related to the formation of the hydration product and carbonatation of the fibers, which cause a densification of the composites.

Accelerated aging of fiber cement composites can cause increment in the density as well, contrary to the water absorption and apparent porosity which decreases (Tonoli, 2019); however, with natural weathering aging water absorption and apparent porosity increases, which was observed by Tonoli as well; although, the density decreases; which is contrary to the result observed in this study. Due to a carbonatation mechanism, some metastable product like ettringite and calcium silicate hydrate (C-S-H) can decompose; which in the end can cause high water absorption and high apparent porosity (Tonoli, 2019, Taylor 1997).

The secondary effects on increasing the apparent porosity and the water absorption of the samples with aging time, are the higher values of swelling over time as well, although the values obtained are lower than the recommendation of ISO 8335 (<2%).

3.3 Mechanical Properties

3.3.1 Stress – strain curves

Typical stress – strain curves are showing in Figure 4. It is evident that to higher percentage of reinforcement, ductility increases; instead, samples with 6 %wt shows a sudden and brittle failure. On the other hand, it is clear the difference between aged and unaged samples. With aging, samples gain stiffness and strength (Akers, 1989; Savastano, 2016); however, they lose ductility drastically, especially for the 9 %wt samples. Meanwhile, outdoor aged samples present an overall high strength compared to the samples aged indoor.

Lima is a highly densely populated city with the Pacific Ocean on the west, these especial conditions makes the city environment very aggressive, according to the measurement performed by SENAMHI and Lima city administration. Along the city, there are high concentrations of carbon monoxide (CO, 1300 to 4684.3 μg/m^3), hydrogen sulfide (H_2S, 40.89 to 120 μg/m^3) and nitrogen dioxide (NO_2, 45 to 210 μg /m^3); combined with sea water particles (chloride ions) make the environment acid; these conditions can reduce the surface alkalinity of the boards, maintaining the fibers with minimum damage. According to the study developed by Zuwonski et al., 2018, environment can produce progressive natural carbonatation through the thickness, which improve fiber/matrix interlocking at the interface, reducing significantly the fiber pull out for the samples with 6 and 9 %wt. As shows Figure 1(b) samples aged at the indoor and outdoor environment with 9 %wt of reinforcement, after the matrix failure, fibers still take some load, as shows the stress-strain relation between 0.001 to 0.002 of strain.

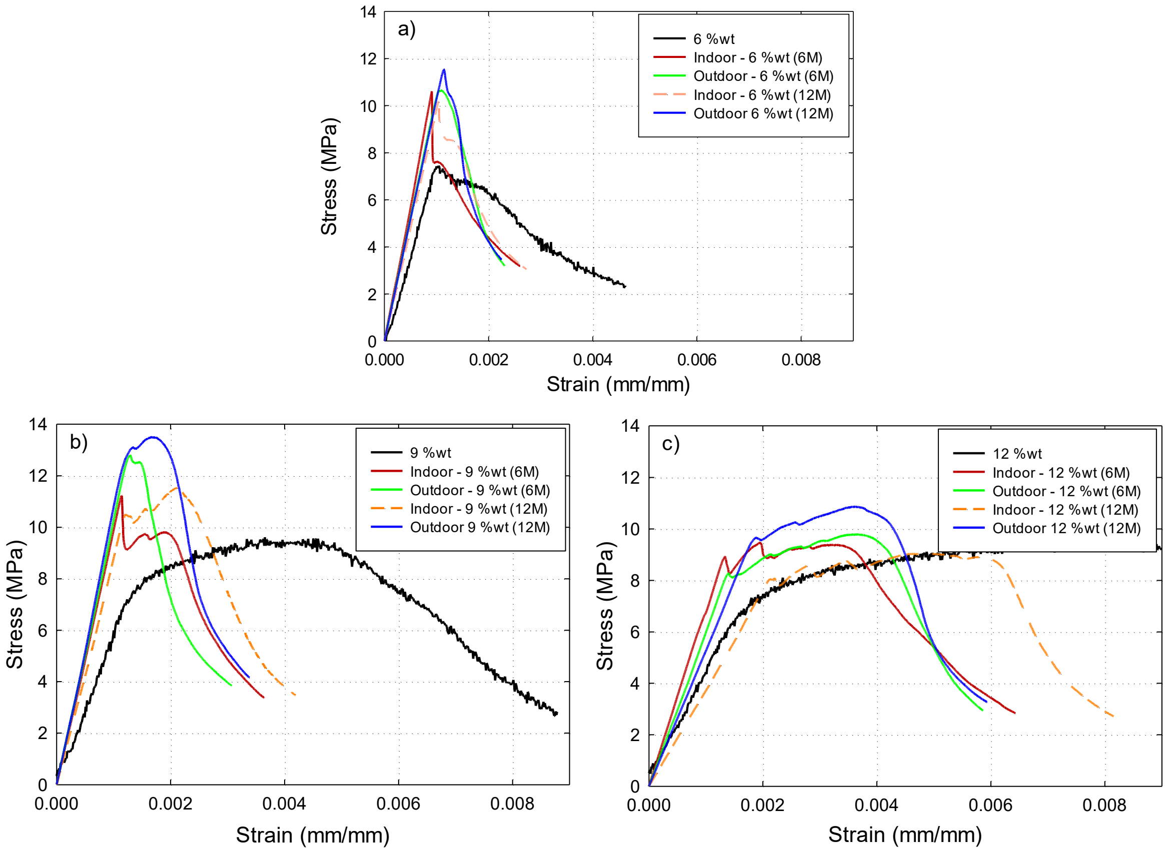

Figure 4. Typical stress - strain curves for evaluated non-aged and six and twelve months (6M, 12M) aged samples, a) 6 %wt, b) 9 %wt and c) 12 %wt

3.3.2 Limit of proportionality (LOP) and modulus of elasticity (MOE).

Improvement in the fiber/matrix interaction may increase the limit of proportionality; as shows in the Figure 5, the value of LOP increases with the aging time, there are no significant differences between the results for the indoor and outdoor aging condition. On the other hand, at the early stages of aging, the LOP is higher for lower ratio of reinforcement; however, over time, especially at outdoor environment, the LOP for 9 %wt keep increasing, while for the 6 %wt decreases. According to Tonoli et al. with aging, calcium re-precipitation into the fiber/matrix and fiber lumen may occur (Tonoli et al., 2019); with a subsequent petrification of the fibers; furthermore, matrix densification can happen around the fibers/matrix interface (Bentur and Akers, 1989); those plays a special role, avoiding the fiber pull out, and improving the interlocking mechanism. On the other hand, at the early stages, lignin can suffer degradation due to the alkali environment (Bentur and Akers, 1989); which, in the end, can cause a premature failure of the fibers; however, as show Table 1, the lignin content in the treated fibers is considerable low, therefore the degradation can shift to the hemicellulose and cellulose directly.

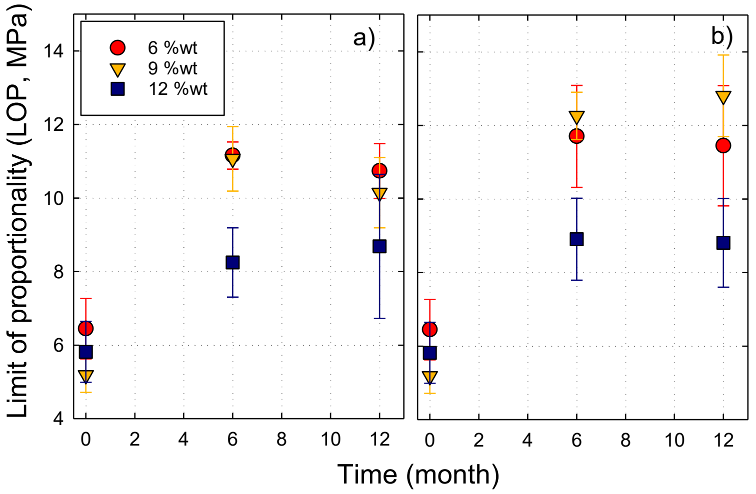

Figure 5. Variation of limit of proportionality over time a) laboratory environment (indoor), b) outdoor environment.

Higher strength at the fiber/matrix interface not only can increase the LOP, but the stiffness can also be improved. Figure 6 shows how the modulus of elasticity increases with aging time. For the 6, 9 and 12 %wt there are no main differences in the trend; however, after 12 months of aging, MOE reduces in their value for all samples, compared to the 6 months of aging; although, samples with 9 %wt and aged in outdoor environment shows better MOE. Depending of the manufacturing process and the materials quality, the stiffness of the lignocellulosic fiber cement composites can vary from ~ 1 to ~ 27 GPa (Hasan, 2021, Tonoli, 2007); in this study, the values obtained are in the average reported in the literature.

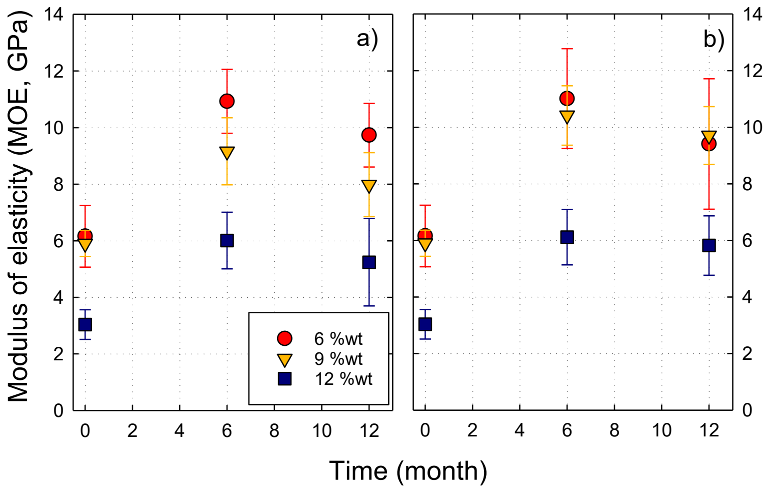

Figure 6. Variation of modulus of elasticity over time a) laboratory environment (indoor), b) outdoor environment.

3.3.3 Modulus of rupture (MOR) and flexural toughness.

As observed in the Figure 7, the modulus of rupture increases with time in samples aged in outdoor environment, keeping the 9 %wt of reinforcement with the best behavior. On the other hand, samples aged at the indoor environment don't show changes for the 9 and 12 wt%, although, there is an increment for the 6 %wt. The carbonatation process is progressive, as observed by Zukowski (Zukowski et al., 2018); contrastingly, during the flexural test, the outer layer is subjected to the maximum stress, which cause the failure; therefore, progressive carbonatation over time may not be reflected in the MOR value.

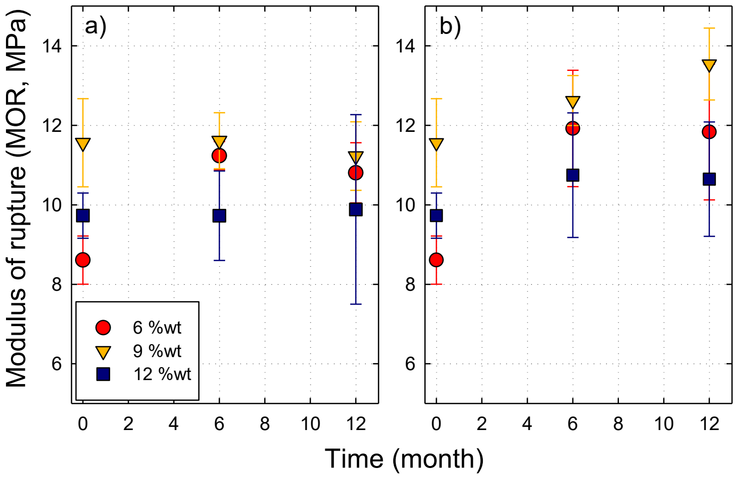

Figure 7. Variation of modulus of rupture over time a) laboratory environment (indoor), b) outdoor environment.

Figure 8 shows the flexural toughness over time, there are no changes in the toughness for samples with higher content of reinforcement (12 %wt). Samples with 9 %wt shows and reduction in their toughness, although samples exposed to outdoor environment shows higher reductions. On the other hand, trends are quite similar to the indoor and outdoor samples for the 6 %wt. Toughness measured in this study is considerable higher compared to the reported to plain matrices (0.02 – 0.04 kJ/m2) (Savastano et al., 2016); although, they are similar to the values obtained for fiber cement reinforced by sisal pulp (Santos et al., 2015).

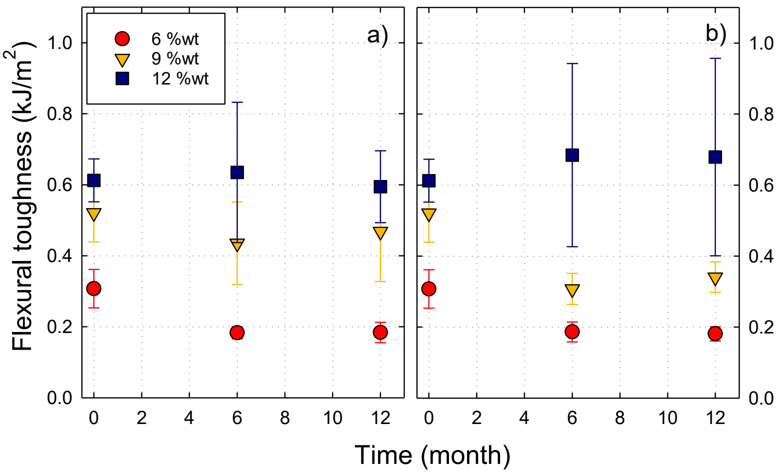

Figure 8. Variation of flexural toughness over time a) laboratory environment (indoor), b) outdoor environment.

3.3.4 Specific Impact strength.

Impact strength has a particular behavior as show Figure 9, at early stages, there is a clear difference in their values between 6, 9 and 12 %wt; however, with the aging time, these differences are reduced. Partial carbonatation contributed significantly to the toughness, since the surface and subsurface gain strength losing ductility due to the progressive carbonatation and embrittlement, the inner part still maintains their ductility; therefore, this combination gives to the composite unique benefit to increase the toughness; albeit, with complete carbonatation these benefits will be lost, as happen for 12 months of exposure.

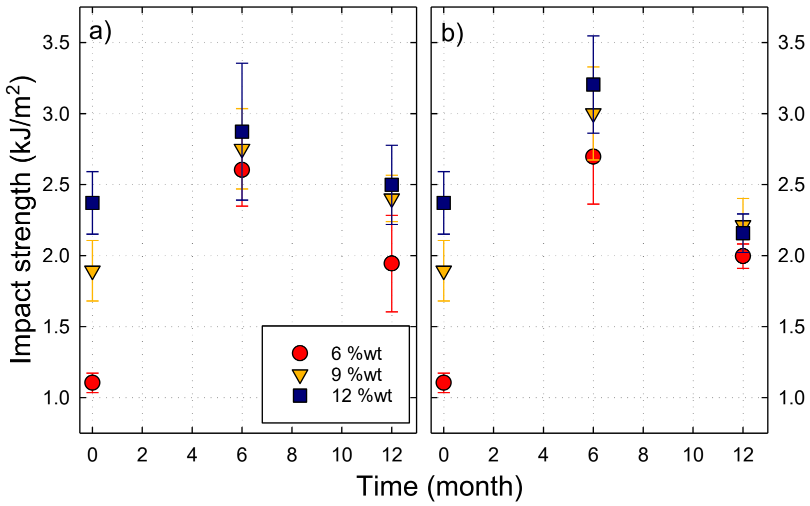

Figure 9. Variation of impact strength over time a) laboratory environment (indoor), b) outdoor environment.

According to the results, to produce Ichu pulp require low aggressive mercerization treatment (0.5M NaOH), compared to the treatment in other natural fibers (Noori, 2021, Madhu, 2019). Since the raw materials present a relative high percentage of cellulose already; besides, in their natural state the Ichu fibers are porous (Charca et al., 2015), therefore sodium hydroxide solution can diffuse easily into the fibers a reach faster to the technical fibers and produce defibrillation. On the other hand, during the process of shearing defibrillation (pulping by blender), it is still required a high amount of energy, in which has a room to improve and optimize this process especially for this type of fibers.

It is also important to say that these results regarding the aging cycles were limited by the methodology used, since they were performed manually when the ideal would be to have the necessary equipment to perfom the aging cycles automatically.

In overall, composite board manufactured shows acceptable physical and mechanical properties according to the Peruvian and international standards (NTP ISO 8336, ASTM C1186 and NBR 5640). Unfortunately, due to the pandemic consequence, it wasn't possible to develop the micrography fracture study using SEM, since it is necessary to take the images immediately after the flexural and impact test. Optical micrography was an alternative; however, a limited and nonclear information was revealed; therefore, these results weren't presented in this study.

4. CONCLUSIONS

In this paper, the feasibility to use Ichu fiber as reinforcement of cement matrix was evaluated on the application of an Andean grass. It can be concluded from this study that fiber pulping process was successfully implemented for the Ichu raw fibers, obtaining over 70 % of the fibers with aspect ratio over 80; although finer particle (aspect ratio < 20) still represents certain percentage (~18 %).

In terms of mechanical properties, the progressive embrittlement of the samples with the aging time was identified with the stress-strain curve and the impact strength, showing a higher impact strength for 6 months of aging when the samples are partially carbonated (surface and sub-surface).

Ichu fiber cement composite boards were manufactured effectively, considering three weight fractions (6, 9 and 12 %wt), and the aging process was evaluated considering the indoor (laboratory environment) and outdoor environment. Composites manufactured with 9 %wt show better behavior compared to the 6 and 12 %wt in their mechanical behavior, with ~11.5 MPa and 13.5 MPa in modulus of rupture for non-aged (cured samples) and aged in outdoor environment respectively; furthermore, the modulus of elasticity increased with the aging time in all the samples.

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