COMPRESSIVE STRESS STRAIN BEHAVIOR OF WORKABLE BIO-CONCRETES PRODUCED USING BAMBOO, RICE HUSK AND WOOD SHAVINGS PARTICLES

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Abstract

The present study aims to produce workable bio-based concretes with consistence indexes around 265 ± 15 mm, free of pressing process with bio-aggregates such as bamboo particles, wood shavings and rice husk. To produce the concretes, a nominal water-to-cement ratio of 0.45, a cement amount of 687 kg/m^3 and a volume fraction of the bio-aggregates of 50%, were used for all mixtures. Appropriate compensating water amounts and the use of adequate dosages of viscosity modifying agent (VMA) allowed obtaining bio-concretes of high workability without exudation and segregation. The fresh property used was the consistence index through the flow table test, while the hardened property determined was the compressive stress-strain behavior at 1, 7 and 28 days. The results showed workable and consistent mixtures, with mechanical properties that can allow industrial scale production of construction components.

Keywords:

Cementitious composites, bio-aggregates, workability, compressive strength

1 INTRODUCTION

The growing increase of ecological awareness has transformed the concept of disposable goods into reusable goods and, this is also applied in the case of agro industrial waste where, for example, the vegetable biomasses are employed as raw materials in the construction sector [Magniont 2010].

According to [Amziane 2016], the global warming, energy savings, and life cycle issues are factors that have contributed to the rapid expansion of plant-based materials for buildings, which can be qualified as environmental-friendly and efficient multifunctional materials.

Some of the biomasses, usually, employed for the production of cementitious composites are: wood shavings, bamboo particles and rice husk. In fact, these lignocellulosic materials are, generally, available in large quantities. Moreover, the resulting bio-based composites are lightweight with a low thermal conductivity, while at the same time still presenting an adequate mechanical performance.

According to studies reported in the literature, the use of these biomasses requires some type of treatment, able to remove inorganic substances and water soluble extractives, with the purpose of improving the compatibility of these raw materials with the cement matrix. For example, [Silva 2004] studied the cement-biomass chemical compatibility using several types of biomasses (coffee husk, rice husk and bamboo). The authors concluded that the treatment that provided the highest value of ultrasonic wave speed and compressive strength was the hot water washing combined to the addition of 3% of $CaCl_2$ in the composite. Then, [Lilge 2009] evaluated the performance of panels composed by cement and different proportions of two combined wooden species with rice husk, using pressing process. The author found that the higher the rice husk addition, the lower the absorption and thickness swelling. The opposite effect was observed for mechanical resistance.

Another important point is that the compaction mode used in the production of low density cement biomass composites reflects the properties required for the material. The high intensity of vibration during the compaction can segregate the mixture, because of the lower densities of the biomasses when compared with the cement paste, while the compaction by pressing reduces the volume of voids.

The compaction by pressing is a widely applied technique dominated by the construction sector in the production of cementitious bio-based composites. That technique implies a greater time and energy consumption in the production process. In order to enable the production of the composites in an accessible, simple and practical way, it is essential for the composite to be workable. The workability extends the field of production and application of this type of composite.

In view of the above, the present study aims at demonstrating the feasibility of producing bio-based cementitious composites with adequate workability.

Particularly, three types of biomasses were used (bamboo particles, rice husk and wood shavings) and, once reached the required workability, the results in terms of both density and mechanical behavior under compressive loads were analyzed.

2 MATERIALS AND METHODS

2.1 Bio-Aggregates: raw materials

Three types of biomasses have been employed in this study as Bio-Aggregates: Bamboo Particles (BP), Rice Husk (RHu) and Wood Shavings (WS).

The bamboo specie was the *Dendrocalamus Asper* coming from Rio Grande do Sul (Brazil). The BP were obtained from the waste of the stems cutting process (stems length around 30 m). Once in the laboratory, the stems wastes (length around 45 cm) were reduced first in particles with length between 5 and 19 mm using an industrial crusher. Then, in a knife mill, these particles were refined to obtain aggregates with a maximum diameter of 4.75 mm (Figure 1a and Figure 2). The apparent density of the BP was 580 kg/m^3 and the moisture content 12.21%.

The RHu was obtained from rural producers of São Paulo (Brazil). The rice husk was characterized by a narrow length distribution between 5–8 mm and a maximum width about 4 mm (Figure 1b). The apparent density of the RHu was 300 kg/m^3 with a moisture content equal to 12%.

The WS were derived from woodworking activities of carpentry in Rio de Janeiro (Brazil). The specie used was the *Pinus elliottii Engelm*. In order to reduce the average the of water absorption of WS, the particles characterized by a nominal diameter lower than 1.18 mm were removed due to their higher specific area (Figure 1c and Figure 2).The apparent density of the WS was 550 kg/m^3 meanwhile its moisture content was 14%.

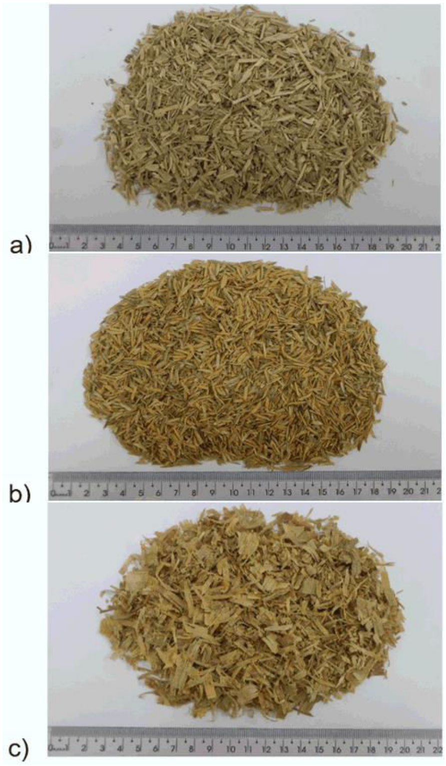

Fig. 1: a) Bamboo Particles b) Rice Husk c) Wood Shavings

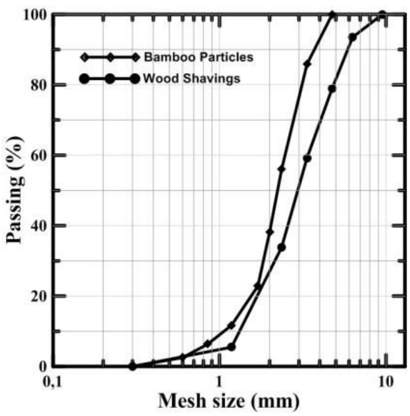

Fig. 2: Granulometric curves of the WS and the BP

2.2 Bio-Aggregates: treatment

The Bio-Aggregates (BA) were washed in hot water (80°C) with the purpose of removing the water-soluble extractives which inhibit the cement setting. [da Gloria 2016] suggested to access first the amount of the water-soluble extractives in order to determine the more efficient washing number for each bio-aggregate. According to the author, after 5 washings, there is no significant extractives removed, therefore five cycles of washing were done. From these 5 washing, it was defined that the number of washing would be that which withdraws 75% of extractives.The BA/water proportion used was 100g/litre as proposed by [Beraldo 1996]. After each washing, the waste water was separated, filtered through the 150 µm mesh, refreshed and stored in plastic bottle of 350 ml. From the waste water, 3 samples of 35 g were weight to the nearest 0.1 mg into a recipient. Then the samples were dried at 40º ± 2°C during 48 h in order to eliminate the water by evaporation and determine the residual extractives mass. The extractives contents were calculated as expressed in the Equation 1.

$$e\% = \frac{m_1}{m_2}.100 \qquad (1)$$

Where: e% = Extractives content, %; m_1 = Mass of waste water residues after drying, g; m_2 = Mass of waste water, g

2.3 Bio-based cementitious Composites

Three types of bio-based cementitious composites were produced by using the abovementioned biomasses as aggregates (i.e., Bio-Aggregates, BA). The cementitious composites were produced with common Portland cement labelled CPV-ARI in accordance with the National Brazilian Standards [NBR 5733]: the adoption of this type of binder is mainly related to its high initial resistance that is generally adequate for prefabricated elements. Moreover, with the purpose of providing the required consistence at the fresh state, a viscosity modifying agent (VMA) named Rheomac UW 410 was used, while calcium chloride CaCl2 was incorporated in the wood shaving composites as setting accelerator.
Based on the literature, a cement-to-biomass ratio equal to 2.5 is one of the most used to produce bio-based cementitious composites ([Sotannde 2012], [Latorraca 2000], [da Gloria 2016], [Andreola 2016]). Considering this ratio and a nominal water-to-cement ratio equal to 0.45, the mixture composition adopted for the production of bamboo particles cement composites (BPCC) was calculated. Furthermore, both the cement content obtained (687 kg/m^3) and the volumetric fraction of BA (50%), were applied to formulate the wood shavings cement composites (WSCC) and the rice husk cement composites (RHCC), in order to have the same volumetric proportions of materials.

For the concrete mixtures of this study, the goal was to obtain consistence indexes around 265 ± 15 mm, indicative of a good workability. Flow table tests were performed according to the Brazilian standard ABNT NBR 13276 - 2016.

Using the concept suggested by [Wolfe 1999] cited by [Souza 2006], the water in wood cement composite mixtures have to be sufficient to keep the fibers saturated, allow the cement hydration and also to guaranty the consistence of the mixture. In the present study, the total water contain was determined considering the nominal free water needed to hydrate the cement and an additional amount of water (named compensating water) that depends on the water absorption capacity of the biomass. As initial trial, it was used as compensating water, the one necessary to saturate the biomass after 24 hours (surface-dry condition). For the BP, the 24 hours water absorption capacity was enough to guarantee to the BPCC, the target spreading of 265 ± 15 mm. On the other hand, for the other two BA, in order to reach the desired spreading, even more water was necessary: for the WSCC and RHCC, the compensating water was 30% and 100% higher than the 24 hours saturating water (surface-dry condition), respectively. The absorptions at saturated-surface-dry condition for the BP, WS and RHu were, respectively, 110%, 70% and 114%. To avoid exsudation different dosages of VMA were used depending on the biomass type. It was added 0.125%, 0.20% and 0.25% (by the cement weight) for BPCC, WSCC and RHCC, respectively. The mixtures compositions of the bio-based cementitious composites produced in the present study are summarized in the table 1.

Table 1: Mixture composition (kg) per cubic meter

	RHCC	BPCC	WSCC
Cement	687	687	687
Bio-aggregates	150	285	275
Nominal free Water	309.15	309.15	309.15
Compensating Water	342	313.5	275
VMA	1.72	0.86	1.37
$CaCl_2$	-	-	20.61

2.4 Samples fabrication and characterization tests

To produce the bio concrete, after a hand mix of the dry bio-aggregates and the cement, the mixture was introduced in a 5l mixer. In the first 1 min 30s, the water was slowly added, followed by the addition of the VMA at the 5th min. The mix continued until reach 8 min of total time.

The fresh composites were molded in cylindrical molds measuring 5 x 10 cm (diameter x height), in three layers. Each layer was vibrated mechanically on a vibratory table (68 Hz) during 10 seconds. The composites were kept in the molds, protected to the humidity and demolded after 24h. Some specimens were tested at 1 day of old, while others were cured into a vapor chamber at 20 ± 3°C and 95 ±2% RH until they reached 7 and 28 days of old.

To measure the composites densities, 4 samples per composite were dried during one week at 100°C until constant mass. Then, the samples were weight to the nearest 0.01g, and the dimensions measured with a paquimeter.

The compressive tests were realized on four samples per composite using the universal testing machine Shimadzu-1000 kN, at the speed of 0.1 mm/min. The compressive strength and the elastic modulus were determined according to Brazilian standard ABNT NBR 5739 - 2007.

3 RESULTS AND DISCUSSIONS

3.1 Extractives measurement

After the multiple washings of the three BA in hot deionized water, it was observed a gradual variation of the water coloration. It can be seen in the Figure 3 starting from the left to the right, that the first wastewaters were dark, and got clearer as the washings were done. As observed by [da Gloria 2016], the change of the color shade can be explained by the fact that the washings removed a significant amount of water soluble extractives as the extractives responsible of color. From the Figure 4, it can be observed a high decrease of the extractives amount after the first washing. In fact, around 75%, 65% and 43% of the extractives from the RHu, the BP and the WS were removed respectively. According to the results, it was decided to wash once the RHu, and three times the BP and WS. The presence of a higher amount of extractives in the WS required the use of an accelerator as the WSCC presented some difficulty for demolding after 24h. Then, 3% (by the cement weight) of calcium chloride was added to the water during the mixture process (see Table 1).

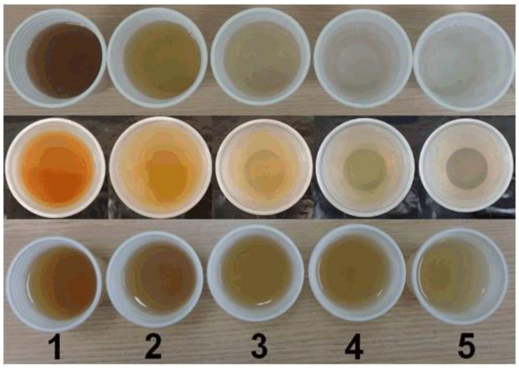

Fig 3: Waste water of RHu, BP and WS after multiple washing cycles

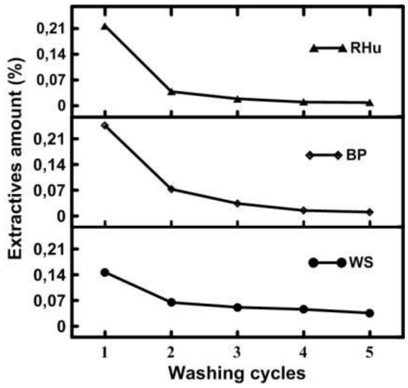

Fig 4: Extractives amount in the waste water

3.2 Workability

The desired workability of the fresh composites had been reached and presented the spreading showed in the Figure 4. The consistence indexes are listed in the table 2.

a)
b)
c)

Fig 4: Spreading of the composites a) RHCC b) BPCC c) WSCC

Table 2: Consistence indexes (mm) of the composites

	RHCC	BPCC	WSCC
C. Indexes	264	265	271

According to the results, the composites showed the desired consistence, between 250 and 280 mm. The RHCC and WSCC presented similar index, while the WSCC showed the highest. Few differences were observed comparing the total waters (nominal free + compensating) between them. This fact can be attributed to the equal aggregates proportions used for all the mixtures. From the results, it can be conclude that it is possible to obtain a good consistence of the fresh composites using the adequate additional water.

3.3 Density

The densities of the BACC are listed in the Table 3.

Table 3: Density (g/cm^3) of the BACC

RHCC	BPCC	WSCC
0.69	0.71	0.82

From the table 3, we can observe that the composites showed densities ranging from 0.69-0.82 kg/m^3. The RHCC presented the lowest density and it can be explained by the fact that the rice husk had the lowest densities, and also the highest total water content. Although the WS are lighter than the BP, the WSCC showed the highest density, probably because of the higher porosity create in the BPCC. The result obtained for the mix WSCC is similar with the result obtained by [Tamba 2007], who found a density equal to 0.795 g/cm^3 for wood cement composites with cement/wood ratio of 2.5. The authors used pre-wetted wood shavings without pressing. [Sotannde 2012]. With the same cement/wood ratio, but with 24h of the composites pressing, the authors obtained a density of 1.1 kg/m^3.

3.4 Compressive stress-strain behavior

The compressive strength and the Young modulus are summarized in the table 4 while the stress–strain curves are show in the Figure 5.

Table 4: Compressive strength and Young modulus and variation coefficient in brackets

Composites	Old (days)	Compressive strength (MPa)	Young Modulus (GPa)
RHCC	1	0.40 (8.35)	0.41 (10.75)
	7	1.44 (6.84)	1.11 (10.41)
	28	2.25 (7.68)	1.60 (4.52)
BPCC	1	1.09 (5.67)	0.92 (3.83)
	7	2.45 (4.57)	1.41 (4.26)
	28	3.25 (4.10)	1.84 (6.06)
WSCC	1	1.18 (5.92)	1.17 (10.72)
	7	4.00 (3.82)	1.88 (5.81)
	28	4.14 (3.04)	2.33 (6.83)

It can be seen from the Table 4 and the Figure 5 that the compressive strengths were below 4.5 MPa for all BACC. From 1 to 7 days, the strength rose respectively 3.6, 2.25 and 3.4 times for the RHCC, BPCC and WSCC. Similarly, the Young modulus increased 2.7, 1.53 and 1.6 times for the RHCC, BPCC and WSCC, respectively.

From the 7th to the 28th day, the strengths increased lower. The RHCC, BPCC and WSCC had reached respectively 64%, 75% and 96% of their 28 days strength, at only 7 days. This behavior may be attributed to the use of high initial strength cement, which allowed the composites to reach in few days, elevated strength. In the case of the WSCC, the 96% observed can be due to the effect of the setting accelerator used. The Young Modulus showed the same tendency like the strengths. From the results, it is observed that 70%, 76% and 80% of the Young Modulus were reached for respectively the RHCC, BPCC and WSCC.

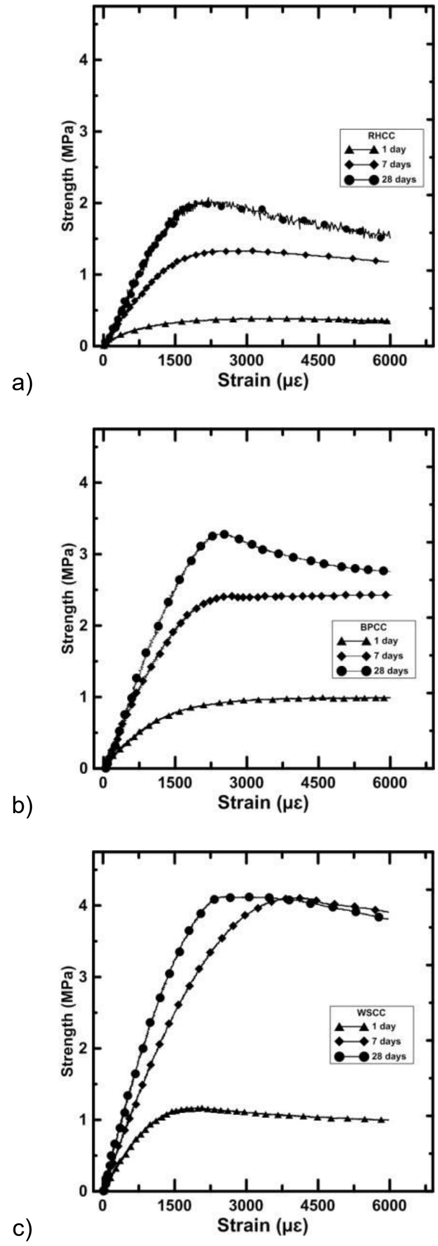

Fig 5: Stress-Strain curves
a) RHCC b) BPCC c) WSCC

The compressive strengths at one day were about 0.4 – 1.18 MPa. The stress-strain curves at 1 day showed a linear behavior until 40% of the maximum strength, followed by a non-linear behavior. For both RHCC and BPCC, at the peak stress a kind of plateau between 2000-2500 and 6000 με is observed in the stress-strain curve. In the range of strain the load is increased only marginally. Thereby, it can be concluded that at 1 day these composites showed a nearly elastic-plastic behavior. However, the WSCC showed a peak stress at 1880 με and from 1880 to 6000με the stresses decreased by about 15%.

At 7 days the strains at the peak stresses for the RHCC, BPCC and WSCC bio-concretes were, respectively, 2380με, 3890με, and 3938με. Moreover, the stress-strain curves showed a linear behavior until half of the peak stress. At 28 days, the composites presented a linear behavior until 65% of the peak stress. From the peak strain until a deformation of 6000με, the RHCC and BPCC showed a 22% of decrease in the compressive load, while for the WSCC mix this decrease was only 7%.

Comparing the strength at 28 days of the BACC, the WSCC presented the highest compressive strength, while the BPCC and the RHCC were respectively 21% and 45% lower. This result can be due to the use of the accelerator for the WSCC that favored a faster hydration of the cement. The low resistance showed by the RHCC mix may be attributed to its high water content that had allowed, by one hand, a good consistence, but by the other hand, created a higher porosity after the sample drying.

The compressive strength values obtained at 28 days are lower than the results of the literature value. Most of the authors didn't produce their composites with the purpose of the good workability and consistence at the fresh state. Moreover, they used to press the fresh mixture for 24h at 40 kgf/cm^2 ([Souza 2006], [Santos 2008], [Macêdo 2012]). For similar cement and wood shavings proportions, [Pomarico 2013] found around 10.75 MPa for pressed wood composites, while [da Gloria 2016] obtained 9.5 MPa for hand compacted composites with pre-wetted shavings.

The specific strength (strength-to-density ratio) and specific stiffness (Young modulus-to-density ratio) at 28 days are summarized in the Table 5.

Table 5: Specific strength and specific stiffness

	RHCC	BPCC	WSCC
Specific strength (kN.m/kg)	3.3	4.5	5
Specific stiffness (kN.m/g)	2.3	2.6	2.8

According to the Table 5, the WSCC presented the highest specifics strength and stiffness. The RHCC and BPCC showed respectively 35% and 10% lower specific strength. Moreover, the specific stiffness of the RHCC and BPCC were 18% and 7.5% lower, respectively, than that of the WSCC. All the BACC showed a directly proportional relationship between mechanical resistance and density.

4 CONCLUSION

This study presented the results of an experimental campaign in which workable bio-based cementitious composites, including several types of bio-aggregates (bamboo particles, wood shavings and rice husk), were produced.

Based on the results obtained herein, the following main points can be remarked:

- The results indicated that it is possible to produce workable bio-based concretes of easy moldability. But, it is worth highlighting that the use of different biomass required however different level of compensating water in order to obtain the required spreading;
- The use of viscosity modifier agent was fundamental to avoid segregation and exsudation;
- Based on the results of the dry density, all the produced BACC can be classified as lightweight materials, according to the RILEM Functional classification (1978);
- It was also observed that both compressive strength and Young modulus increased over time. The increase range of the Young modulus of the BACC was lower than the range of their strength increase. Similar tendency was observed for the specifics strength and stiffness.

5 REFERENCES

[Amziane 2016], Sofiane, A.; Sonebi, M.; Overview on bio-based building material made with plant aggregate. RILEM Technical Letters (2016) 1: 31 – 38

[Andreola 2016] Andreola, V. M.; da Gloria M. Y. R.; Toledo Filho R. D.; Desenvolvimento de biocompósitos contendo partículas de bambu. In: II Congresso Luso-Brasileiro de Materiais de Construção Sustentáveis, 2016, João Pessoa, Brasil.

[Beraldo 1996] Beraldo, A. L., Bartholomeu, A., Batista A., Fagundes A., Rolim M., Segantini, A; Viabilidade de Fabricação de Compósitos Resíduos de Madeiras e Cimento Portland (CBC). In: Workshop reciclagem de resíduos como materiais de construção civil, 1996, São Paulo, Brasil; 77-82.

[da Gloria 2016] da Gloria M. Y. R.; Toledo Filho R. D.; Influence of the wood shavings/cement ratio on the thermo-mechanical properties of lightweight wood shavings-cement based composites. In: 6th Amazon & Pacific Green Materials Congress and Sustainable Construction Materials Lat-Rilem Conference; April 27-29th 2016. Cali, Colombia; 365-374.

[Lilge 2009] Lilge, D. S.; Desempenho de duas espécies florestais em combinação com casca de arroz na fabricação de painéis cimento-madeira, Universidade Federal de Santa Maria, 2008.

[Macêdo 2012] Macêdo, A. N.; Souza A. A. C.; Pompeu Neto, B. B.; Chapas de cimento-madeira com resíduos da indústria madeireira da Região Amazônica, Ambiente Construído, Porto Alegre, v. 12, n. 2, p. 131-150, abr./jun. 2012.

[Magniont 2010] Magniont, C.; Contribution à la formulation et à la caractérisation d'un écomatériau de construction à base d'agroressources, Université de Toulouse, 2010.

[Pomarico 2013] Pomarico, F. A.; Potencial de utilização da madeira de clones de eucalipto na produção de painéis cimento-madeira, Universidade Federal de Lavras, 2013.

[Santos 2008] Santos, R. C.; Aproveitamento de resíduos da madeira de candeia (*Eremanthus erythropappus*) para produção de chapas de partículas, Universidade de Lavras, 2008.

[Silva 2004] Silva, A. P.; José, F. J.; Beraldo, A. L.; Estudos para viabilizar o uso de resíduos agro-industriais em compósitos à base de cimento portland. In: Congresso Brasileiro de Ciência e Tecnologia em Resíduos e Desenvolvimento Sustentável, 2004, Florianópolis, Brasil.

[Sotannde 2012] Sotannde, O. A.; Oluwadare, A. O.; Ogedoh, O.; Adeogun, P. F. Evaluation of cement-bonded particleboard produced from afzelia africana wood residues, Journal of Engineering Science and Technology 2012, Vol. 7, No. 6, 732 – 743.

[Souza 2006] Souza, A. A. C.; Utilização de resíduos da indústria madeireira para fabricação de chapas cimento madeira, Universidade Federal do Pará, 2006.

[Tamba 2007] Tamba, S.; Voumbo, L. M.; Wereme, A.; Gaye, S.; Sissoko, G.; Durabilité des bétons legers a base de copeaux de bois, 2007, Journal des Sciences Vol. 7, N° 4, 67 – 72.