PARTIAL REPLACEMENT OF CEMENT BY COMBINATION OF FLY ASH AND METAKAOLIN IN BAMBOO BIO-CONCRETES

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Abstract
During the Portland cement manufacture, it is known that an average of one ton of CO2 is released per ton of cement produced. Consequently, the materials with high cement consumption have negative environmental impacts. One of these materials is the bio-concrete of bamboo, which is basically constituted of bamboo particles, an average of 800 kg/m^3 of cement, and presents around 9 MPa of compressive strength. In this work, a partial replacement of cement with fly ash and metakaolin was realized, with the purpose of reaching compressive strength closer to a bio-concrete containing only cement. Mixtures with partial substitution of 0, 40, 50, 60 and 70% of cement by mass were produced with a volumetric fraction of bamboo set as 40%. The water-to-cement ratios varied gradually from 0.30 to 0.40, while the fly ash inversely varied from 40 to 10% of cement replacement by weight and the metakaolin were kept constant (30%). The compressive behavior of the bio-concretes was analyzed at 7, 28, 60 and 90 days. The results revealed that it was possible to reach between 60% and 90% of the reference strength, producing workable bio-concretes using binders with low CO2-emission.

Keywords:
Bamboo, cement, fly ash, metakaolin, bio-concrete

1 INTRODUCTION

The cement production sector is the third largest energy consumer, behind aluminum and steel production sector. The cement industries contribute to the emission of approximately one ton of carbon dioxide (CO_2) into the atmosphere per ton of cement produced.

Growing concern about the high amount of greenhouse gases has led construction actors to find ways to reduce the consumption of Portland cement in construction materials without compromising their properties and performance.

Thus, according to [Amziane and Sonebi, 2016], global warming, energy savings, and life cycle are factors that have boosted the rapid expansion of plant-based materials. An example of this type of material is the bio-concrete consisting mainly of vegetable particles and Portland cement.

In materials which cement consumption is high, the partial substitution of cement by pozzolans reduces environmental pollution and conserves natural reserves. The combination of fly ash and metakaolin with Portland cement also allows increasing the mechanical properties of cement / biomass materials.

Following the studies of [Isaia, 1997] and [Isaia et al. 1999], when a less reactive pozzolan is used with a more reactive pozzolan in a ternary mixture, a synergy between the pozzolans results in an improvement of the mechanical performance of the material.

Azevedo [2002] explained that pozzolanic materials positively affect the mechanical properties and durability of the bio-concretes: (i) contribute to minimizing environmental problems; (ii) control the emergence of exudation and segregation of the mixture due to its higher water absorption capacity; (iii) allow to obtain superior resistances and, in the case of fly ash, an increase of workability of the bioconcrete in the fresh state, facilitating the molding without compaction.

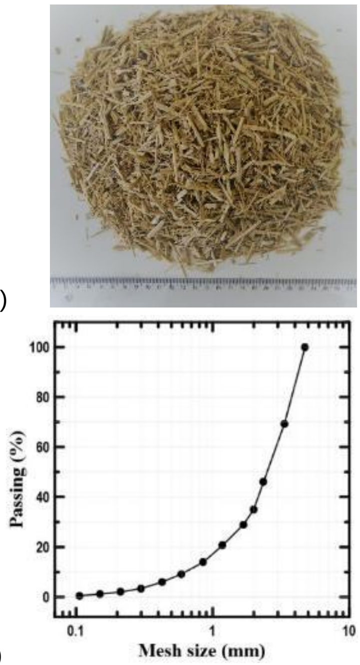
In view of the above, the present study aims to demonstrate the feasibility of producing bamboo bio-concretes with low cement content, by combining cement, fly ash and metakaolin, with the target of obtaining compressive strength closed to that of the bio-concrete containing only cement.

The results were analyzed in terms of mechanical behavior at 7, 28, 60 and 90 days of age.

2 MATERIALS AND METHODS

2.1 Bio-Aggregate: raw material

The bio-aggregates of bamboo used in this study came from the State of Rio de Janeiro (Brazil). The bamboo species were: *Dendrocalamus Asper, Phyllostachys aurea e Phyllostachys edulis.* First, the stems were cut on table saw, in order to reduce their length from 120 cm to 40 cm. After the cut, the stems were processed in an industrial crusher to obtain the first particles with length between 5 and 19 mm. Then, in a knife mill, these particles were refined in a smaller scale to have the bio-aggregates with maximum diameter of 4.75 mm (Fig.1). The apparent density, the water absorption and moisture content were 590 kg/m^3, 81% and 10%, respectively according to the standards NM 52: 2002 and NBR 9939/2001.



(a)

(b)

Fig.1 : (a) Bio-aggregates of bamboo (b) Granulometric curves

2.2 Bio Concrete of Bamboo (BCB)

Based on previous work [Andreola 2017 and Santos *et. al* 2017] the average consumption of cement used in bio-concrete is 800 kg/m³, with an average compressive strength of 5 MPa. These results revealed high cement consumption for a low strength. In order to reduce the cement content, the bio-concretes were produced with commercial metakaolin (Mk) and fly ash (FA), in addition to the Portland cement (PC) CPV-ARI according to the Brazilian Standards [ABNT NBR 5733]. The amount of metakaolin (MK) was as 30% of cement mass according to the good behavior observed by [Lima *et. al,* 2011], while the fly ash (FA) proportions varied (10%, 20%, 30% and 40%). As known the FA presented a slow reactivity and its morphology helps in the workability. Then, the replacement method used consisted in increasing the amount of FA with a simultaneous decrease of the water-to-cement (w/c) ratio, guaranteeing the same range of spreading of the mixtures at fresh state (210 ± 10 mm). The w/c proportions were set as 0.30, 0.32, 0.35, 0.37 and 0.40. Using the concept suggested by [Santos et. Al 2017], out of the hydration water, additional water named compensating water was also used, due to the high water absorption capacity of the bamboo. In fact the compensating water allows to keep the BB saturated, in order to avoid the absorption of the water destined to the cement. The compensating water is equal to the absorption water of BB determined in the section 2.1 (81%). Then, the total water of the mixture was calculated considering the hydration and compensating water. The volumetric fraction of bamboo bio-aggregates was set as 40%.

To obtain a good workability at fresh state, it was necessary to use the superplasticizer Glenium (0.3% of cementitious materials mass) and the viscosity modifying agent (VMA) Rheomac UW 410 (0.1% of cement mass) to control exudation and segregation. Calcium chloride $CaCl_2$ (3% of the cement mass) was used as setting accelerator. The mixtures compositions of the bio-concretes produced in the present study are summarized in Table 1. The nomenclature BCB C*x*-W*y* indicated that the percentage of cement is *x%* and the w/c ratio is *y*.

Table 1 : Mixture composition (kg) per cubic meter

BCB	BB	CEM	MTC	CV	W_T*	SP	VMA
C30-W0.30	236	238	238	318	430	7,95	0,99
C40-W0.32	236	320	240	240	447	8,01	1,00
C50-W0.35	236	398	238	159	470	7,96	0,99
C60-W0.37	236	483	241	80	489	8,06	1,00
C100-W0.40	236	838	-	-	515	8,38	1,04

*W_T = total water (hydration and compensating water)

2.3 Samples fabrication and characterization tests

The production of the bio-concretes began with a mixing of the cementitious materials. Once homogenized, the BB was added and the whole mixed for one minute before introducing the water. The calcium chloride was diluted in one half of the water, while the superplasticizer in the second half. The first half was slowly added for 1min, followed by the second also added for 1 min. After completing 6min of mixing, the VMA was introduced into the mixture and the whole mixed until 8 min of total time.

The consistence of the fresh bio-concrete was analyzed by flow table test according to the Brazilian Standard [ABNT NBR 13276]. The material was molded in three layers in cylindrical molds with dimensions of 75 x 150 mm (diameter x height). Each layer was mechanically vibrated on a vibrating table (68 Hz) for 15s. After molding, the bio-concretes were kept in molds and protected against moisture loss and demolded after 24h. The samples were kept in a room at temperature of 20 ± 3°C and relative humidity of 35 ± 2% until reaching 7, 28, 60 and 90 days of old.

The compressive tests were realized on four samples per composite using the universal testing machine Shimadzu - 1000kN, at the speed of 0.3 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 Workability

It is important to notice that the spreading obtained allow molding easily, without necessity of manual or mechanical compaction. The Table 2 presents the average values of the consistence indexes of the bio-concretes, while the Fig. 2 shows their spreading. It is observed that the higher the percentage of cement, the greater the spreading obtained. All the BCB with cement replacement showed consistence indexes between 200 and 225 mm, and an average of 23% of spreading less than the BCB C100. That difference can be due to the higher water amount in the reference BCB, and the absence of metakaolin, that had a tendency of reducing the spreading. The similar indexes observed within the BCB can be explained by the crossed effects of the FA increase with the water decrease. While the addition of more the FA led to increase the spreading, the diminution of water helped to maintain the spreading in the same range. It is important to notice that the spreading obtained allow molding easily, without necessity of manual or mechanical compaction.

Table 2: Consistence indexes (mm) of the bio-concretes

Bio-concretes	C. Indexes
C30-W0.30	200
C40-W0.32	215
C50-W0.35	222
C60-W0.37	225
C100-W0.40	280

(a)

(b)

(c)

(d)

(e)

*Fig. 2: Spreading of the BCB **(a)** C30-W0.30 **(b)** C40-W0.32 **(c)** C50-W0.35 **(d)** C60-W0.37 **(e)** C100-W0.40*

The results obtained are satisfactory since, in general, the demand of water increases with the increase of the content of pozzolans.

Rajamma et al [2015] studied the influence of the 0%, 10%, 20% and 30% effect of fresh biomass ash from slurries and mortars with water/binder ratios between 0.55 and 0.65. The authors showed that, even with the use of superplasticizer, such dosages were not sufficient to avoid spreading reduction, up to 10% of ash, the influence on the consistence of the mortar is not visible, but when the dosage increases to above 20% the demand also increases significantly.

3.2 Compressive stress-strain behavior

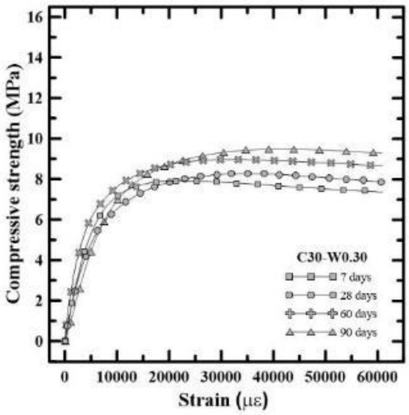
The compressive strength and the Young modulus are summarized in Table 3 while the stress–strain curves are illustrated in the Fig. 3.

Table 3 : Compressive strength and Young modulus and variation coefficient in brackets

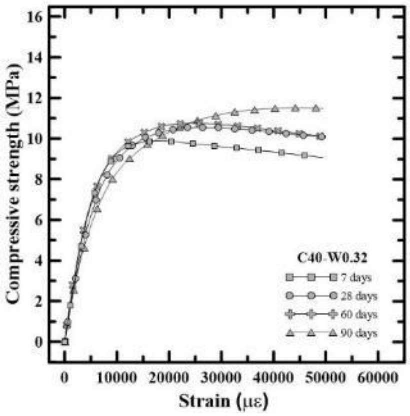
Bio-concretes	Old (days)	Compressive strength (MPa)	Young Modulus (GPa)
C30-W0.30	7	8.15 (1.05)	1.38 (5.82)
	28	8.46 (2.89)	1.55 (6.96)
	60	9.06 (7.01)	1.70 (1.35)
	90	9.60 (4.14)	1.82 (5.33)
C40-W0.32	7	10.20 (1.23)	1.45 (8.45)
	28	10.63 (3.13)	1.48 (4.74)
	60	10.83 (0.18)	1.51 (5.12)
	90	11.67 (1.23)	1.63 (4.08)
C50-W0.35	7	10.62 (1.65)	1.39 (9.74)
	28	10.96 (6.45)	1.55 (5.50)
	60	11.42 (0.84)	1.62 (8.98)
	90	12.35 (8.18)	1.75 (3.87)
C60-W0.37	7	13.16 (0.49)	1.71 (7.83)
	28	13.39 (0.14)	1.95 (4.07)
	60	13.47 (1.96)	2.03 (3.78)
	90	14.25 (0.73)	2.11 (5.48)
C100-W0.40	7	13.49 (2.26)	2.12 (6.83)
	28	14.75 (3.51)	2.15 (7.68)
	60	14.99 (3.87)	2.19 (1.68)
	90	15.25 (2.81)	2.37 (2.61)

According to the results, it can be seen that at 7 days, all the BCB presented an average of 96%, 93% and 88% of the strength obtained at 28, 60 and 90 days, respectively. At 28 days, their compressive strength reached 97% and 92% of that of 60 and 90 days, respectively. This behavior can be attributed to a combined effect of the use of high initial strength cement and setting accelerator. Similar tendency was observed analyzing the elastic modulus. At 7 days, the BCB presented 93%, 89% and 83% of the stiffness observed at 28, 60 and 90 days, respectively. The reference C100-W0.40 showed the highest mechanical performance at all age and the Figure 4.f. emphasized its strength at 28 days. C100-W0.40 presented a compressive strength 9%, 26%, 28% and 43% higher than the C60-W0.37, C50-W0.35, C40-W0.32 and C30-0.30, respectively. Even C60-W0.37 presented 40% less cement than the reference, its strength was much closed. The same fact was observed with C50-W0.35 and C40-W0.32 which contained 50% and 60% less cement than C100-W0.40 but showed 72% and 74% of strength, respectively. These results showed that it is possible to reduce the cement amount until 60% and still have a good mechanical response, even at early age. Such behavior can be explained by the use of calcium chloride in the production of bamboo bio-concretes that accelerates the cement hydration process, releasing early calcium hydroxide which reacts quickly with the amorphous silica present in pozzolans.

[Isaia, 2003] observed that pozzolanic effects increased as mineral addition increased in the blend, being greater after 91 days than after 28 days. The author produced mixtures with 12.5%, 25% and 50% cement substitution by fly ash, rice husk ash and limestone filer, with water / binder ratios of 0.35, 0.50 and 0.65.



(a)



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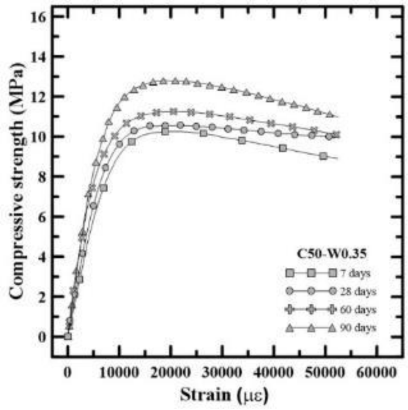

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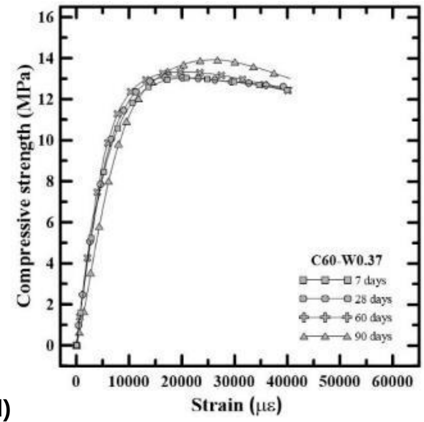

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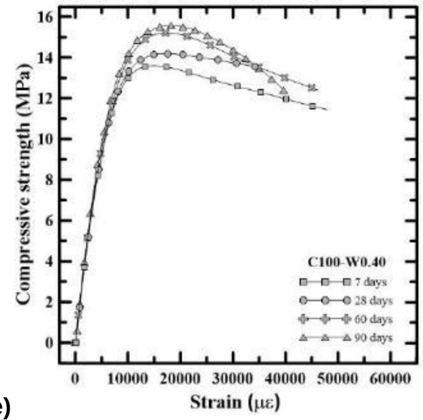

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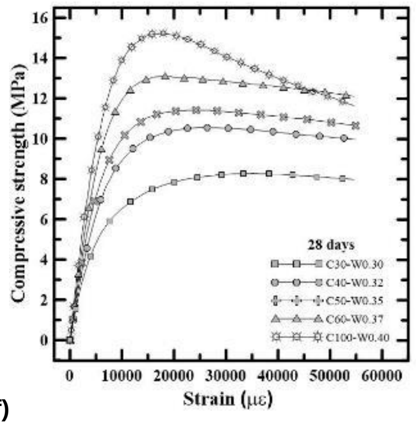

(f)

Fig. 3 : Compressive Strain Curves
(a) *C30-W0.30* ***(b)*** *C40-W0.32* ***(c)*** *C50-W0.35* ***(d)*** *C60-W0.37* ***(e)*** *C100-W0.40* ***(f)*** *All BCB at 28 days*

4 CONCLUSIONS

This paper presented the results obtained in an experimental research in which bio-concretes with pozzolans additions were produced in order to access the effect of cement partial replacement on the BCB workability at fresh state and its strength at early and old age.

Based on the results obtained, it can be concluded that:

- It is possible to produce workable bio-concretes with addition of metakaolin, fly ash and super plasticizer, without necessity of mechanical compaction during the molding;

- Until 60% of cement substitution, the BCB produced presented more than 70% of the strength of the reference BCB. Also, the use of calcium chloride helped to reach at 7 days, 90% of the 90 days strength, showing the mechanical viability of cement replacement by pozzolans in the BCB.

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6 REFERENCES

[ABNT NBR 13276] Argamassa para assentamento e revestimento de paredes e tetos - Determinação do índice de consistência. ABNT 2005.

[ABNT NBR 5733] Cimento Portland com Alta Resistencia Inicial. ABNT 1991.

[ABNT NBR 5339] Ensaio de compressao de corpos-de-prova cilindricos. ABNT 2007.

[Andreola 2017] Andreola, V. M.; Caracterização Física, Mecânica e Ambiental de Bio-concretos de Bambu. Rio de Janeiro: COPPE/UFRJ, 2017.

[Azevedo 2002] Azevedo, A. F. F. L. C. Betões de elevado desempenho com incorporação de cinzas volantes. PhD, Universidade do Minho, Minho, 2002.

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

[Santos et al. 2017] Santos, D. O. J.; Da Gloria, M. Y. R.; Andreola, V. M.; Pepe, M.; Toledo Filho, R. D. Behaviour under Bending Loads of Workable Bamboo Bio-Concrete. Non-Conventional Materials and Technologies: NOCMAT for the XXI Century, v. 7, p. 54, 2018.

[Isaia, 2003] Isaia, G. C; Gastaldine, A.L.G; Moraes, R. Physical and pozzolanic action of mineral additions on the mechanical strength of high-performance concrete. Cement & Concrete Composites 25 (2003) 69–76

[Isaia, 1997] Isaia, G. C; Synergic action of fly ash ternary mixtures with silica fume and rice husk ash: pozzolanic activity. In: Justnes H, editor.International Congress on the Chemistry of Cement, 10th, Gothenburg, 1997, Proceedings, vol. 4, 4iv005. Amarkai AB; 1997. p. 8.

[Isaia et al 1999] Isaia, G. C; Malhotra V. M., Helene, P.; Prudencio, L. R. Synergic action of fly ash in ternary mixtures of high-performance concrete: durability aspects. In: editors. CANMET/ACI International Conference on High-performance Concrete, 2nd, Gramado, 1999, Proceedings. American Concrete Institute; 1999. p. 481–502. (SP-186).

[Lima et al 2011] Lima, A.J.M.; Iwakiri, S.; Lomelí-Ramirez, M.G. utilização de resíduos de Pinus spp., metacaulim de alta reatividade e resíduo de cerâmica calcinada em compósitos cimento-madeira. Madera y Bosques 17(2), 2011:47-65.

[Rajamma et al 2015] Rajamma, R.; Senff, L.; Ribeiro, M.J.; Labrincha, J.A.; Ball, R.J.; Allen, G.C.; Ferreira, V.M. Biomass fly ash effect on fresh and hardened state properties of cement based materials. Composites Part B 77 (2015) 1-9.