revista Matéria
ISSN 1517-7076

Revista Matéria, v. 15, n. 2, pp. 151–156, 2010.
http://www.materia.coppe.ufrj.br/sarra/artigos/artigo11209

Cement composites reinforced by short curaua fibers

A. d'Almeida, R. Toledo Filho, J. Melo Filho

Civil Engineering Department UFRJ/COPPE
e-mail: anafampa@yahoo.com.br ; toledo@coc.ufrj.br ; joaomf@coc.ufrj.br

ABSTRACT

The development of an eco-friendly material that could reduce CO^2 emission and that could aggregate value to a natural fiber, setting man at the countryside and raising the income of populations from poor regions is a challenge. Lignocellulosic fibers are cheap and are a readily available reinforcement, requiring only a low degree of industrialization for their processing. The main drawback of using cement composites reinforced with lignocellulosic fibers is that the fibers can be mineralized inside the alkaline environment. In this work, Portland cement was partially replaced by metakaolinite in order to produce a matrix free from calcium hydroxide, avoiding thus the problem of fiber mineralization. Cement composites reinforced with 2, 4 and 6% of short curaua fibers, were manufactured. The composites were submitted to four pointing bending tests in order to determine their mechanical behavior. The results obtained were compared with those found for cement composites reinforced with sisal fibers.

Keywords: Cement composites, curaua fibers, mechanical behavior.

1 INTRODUCTION

Nowadays there is an increasingly interest in the development of eco-friendly materials. Thus, environmental challenges due to the necessity of reducing worldwide levels of CO^2 emissions, to limit the energy consumption and to use natural materials are promoting an increasingly effort to find viable alternatives to minimize pollution from the main productive processes.

Therefore, researches using lignocellulosic fibers as reinforcement of cementitious composites are increasing [1-4]. Special attention should be given to natural fibers, in respect to energy conservation and environment protection. In fact, these materials possess many advantages, like low density, high specific strength, no healthy hazards, and also availability as renewable resources.

The main drawback to use cement composites reinforced with lignocellulosic fibers is that the fibers can mineralize inside the cement alkaline environment. This is due to the migration of calcium hydroxide to the fiber lumen, middle lamella and cell walls. In this work, 50% of Portland cement (PC) was replaced by metakaolinite (MK), a material with pozolanic activity, in order to produce a matrix completely free of calcium hydroxide, avoiding in this way the problem of fiber mineralization. Moreover, the replacement of Portland cement by metakaolinite reduces CO_2 emissions and increases strength and durability of the material [3, 4].

Cement composites reinforced with 2, 4 and 6% of short curaua fibers, 25 mm and 50 mm long were manufactured and tested. Curaua fibers have been used as reinforcement for polymer composites [5, 6], and are appraised as high strength lignocellulosic fibers [7]. The results achieved were compared with that one obtained by Mello Filho [8] for composites reinforced with short sisal fibers.

2 MATERIAL AND METHODS

Curaua fibers are extracted from the leaves of Ananas erectifolius plants, which are a natural occurring bromeliacea from Amazon region, Brazil. This fiber can reach 1.5 m long. For this work, the cuarua fibers were cleaned in boiling water, brushed and chopped in 25 mm and in 50 mm length.

The matrix was composed by Portland cement (PC) CPII F-32, metakaolinite (MK), river sand with maximum diameter of 1.18 mm and density of 2.67 g/cm^3 and naphthalene superplasticizer (Fosroc Reax

Autor Responsável: Ana Lúcia d`Almeida Data de envio: 25/03/2010 Data de aceite: 26/06/2010

Complast SP 430) with a solid content of 44%. The superplasticizer was used in order to increase the fluidity of the matrix.

The matrix was manufactured in a bench-mounted mechanical mixer with a capacity of 20 liters. The sand and the dry cementitious material were dry mixed during 30 seconds to homogenize the mixture. Then, the superplasticizer diluted in water was slowly poured in the running mixer during 30 seconds and then the mixture was mixed for 1 minute more. At this point the fibers were added to the fresh matrix and mixed for 3 minutes.

The fresh mix was placed in an aluminum mould with dimensions of 400 x 250 x 12 mm and vibrated at a frequency of 65 Hz (Figure 1 shows this procedure). The mould was closed for 24 hours and after this time the composites were demoded and fog cured for 28 days in a cure chamber with 100 RH at 23^{o}C.

(a) (b)

Figure 1: Composites Processing: (a) Mixing a (b) composite.

The reinforced ratio of the composites was 2, 4 and 6% in volume. The mortar matrices used in this work present a mix ratio 1:1:0.5 (M1) (cementitious material: sand: water by weight). Table 1 shows the composites manufactured. The composite with 6% of curaua fibers was manufactured only with 25 mm fibers length.

Table 1: Summary of Composites Manufactured

Composite	Reinforced Ratio (%)	Fiber length (mm)
R2%_25	2	25
R4%_25	4	25
R6%_25	2	25
R2%_50	4	50
R4%_50	6	50

The mechanical behavior of the composites was evaluated after 28 days of aging in a Shimadzu AGX – 100kN test equipment. Specimens 400 mm long, 80 mm large and 12 mm thick were tested in four point bending, at a crosshead rate of 0.5 mm/min. Three specimens were tested with a 300mm span, for each manufactured composite.

From the load deflection curves, the post crack bending strength (PCS), first-cracking bending strength (FCS), displacement at fist cracking and the toughness of the composites were calculated. The toughness was calculated as the area under the load versus displacement curve up to a displacement of 15 mm divided by the transversal section area.

3 RESULTS AND DISCUSSIONS

The results from four point bending tests (mean ± standard derivation), with the respective coefficient of variation (CV, expressed in %) are presented in Table 2. It should be noticed that, depending on the case, values of CV up to 25% are acceptable. Whereas the properties of natural fibers vary considerably and that the composites were hand made manufactured, the values are quite acceptable. The effect of curaua ratio and length on the mechanical properties of curaua reinforced composites can be observed in Table 2 and in Figures 2, 3 and 4**.**

Table 2: Summary of the Four Pont Bending Tests results

Composites	FCS (MPa) (CV%)	δ (FCS) (mm) (CV%)	PCS (MPa) (CV%)	Toughness (kJ/m^2) 15 mm (CV%)
R2%_25	6.59 ± 0.48 (7.28)	0.67 ± 0.05 (7.46)	2.13 ± 0.12 (5.51)	1.05 ± 0.07 (6.87)
R4%_25	4.76 ± 0.51 (10.70)	0.55 ± 0.06 (10.90)	3.20 ± 0.76 (23.75)	1.43 ± 0.29 (20.28)
R6%_25	4.45 ± 0.46 (10.34)	0.60 ± 0.01 (1.67)	3.64 ± 0.57 (15.66)	1.59 ± 0.39 (24.53)
R2%_50	4.77±0.41 (8.66)	0.51±0.02 (3.67)	3.94±0.46 (11.61)	1.58±0.28 (17.68)
R4%_50	4.40±0.38 (8.63)	0.54±0.08 (14)	4.59±0.58 (12.6)	2.13±0.36 (17.04)

Comparing the results from Table 2, it can be noticed that as the fiber volume fraction increases, the FCS decreases from 6.59 ± 0.48 MPa (R2%_25 composite) to 4.45 ± 0.46 MPa (R6%_25 composite), in accordance with what was expected as the introduction of the fibers damage the matrix (9). This is in accordance to the results observed by d'Almeida *et al.* [1]. Also, it is interesting to observe the FCS values for R2%_25 and for R2%_50 composites are 6.59 ± 0.48 MPa and 4.77±0.41 MPa, respectively, which means that the increases of fibers length seems to have damaged the matrix.

Regarding PCS values, it can be observed that, for composites reinforced with 25 mm fiber length, there is an increase of 33.44% and of 41.48% when the volume fraction increases from 2 to 4% and from 2 to 6%, respectively. A similar behavior was observed for cement composites reinforced with short sisal fibers [8]. On the other hand, for the composites reinforced with 50 mm fiber length, an increase of 14.16% was obtained when the volume fraction of fibers increases from 2 to 4%. The increase observed between R2%_25 and R2%_50 in PCS value was 45.94% and between R2%_25 and R2%_50 was 33.28 %. Comparing the effect of volume fraction and length on PCS value, and also observing the curves of equivalent flexural stress versus displacement (Figures 2, 3 and 4), it can be concluded that the critical length for the composites manufactured is higher than 25mm (Figure 2). The a critical length parameter (lc) is the minimum fiber length required to build-up a stress in the fiber which is equal to its strength [9]. The FCS value showed in Table 2 for the composite R4%_50 indicates that possibly the critical length for the composite is 50 mm. The critical volume (V_c) for this fiber length is higher than 2% because PCS value for R2%_50 composite was lower than FCS value, and is likely to be 4%, in view of PCS value was slightly higher than FCS value for R4%_50 composite (Figure 3). Figure 4 shows the effect of fiber length on the stress versus displacement. In fact, critical volume (V_c) and fiber length are linked, as can be seen in equation 1 for 2D random distribution [9].

$$Vc = \frac{\pi}{2}\frac{\sigma_{matrix}}{\tau_{fu}}\frac{1}{l/d} \qquad (1)$$

Where: V_c= critical volume;
σ_{matrix} = First Cracking strength,
τ_{fu} = Interfacial shear stress;
l = Fiber length;
d = Fiber diameter.

Regarding the effect of fiber volume fraction on toughness value, it can be noticed an increase of 26.57% between R2%_25 and R4%_25 composites, 33.96% between R2%_25 and R6%composites and 25.82% between R2%_50 and R4%_50. In respect to the effect of fiber length on composite toughness, it was observed an increasing of 32.86 % form composites R4%_25 to R4%_50.

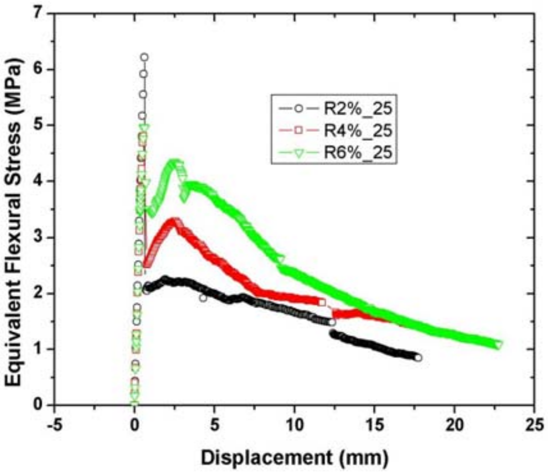


Figure 2: Typical four point bending curves for composites reinforced by 2, 4 and 6% 25 mm length curaua fibers. Effect of the reinforcement ratio on the flexural behaviour of the composite.

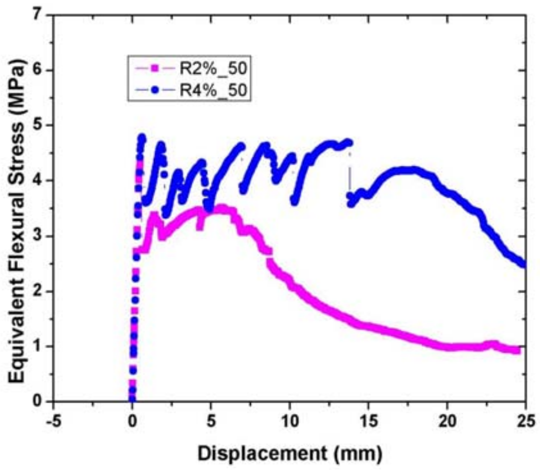


Figure 3: Typical four point bending curves for composites reinforced by 2 and 4% 50 mm length curaua fibers. Effect of the reinforcement ratio on the flexural behaviour of the composite.

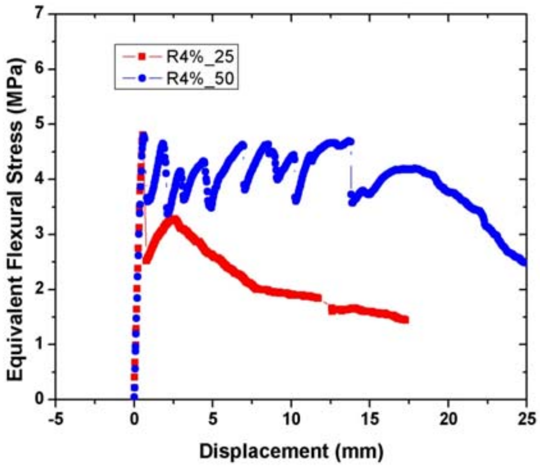


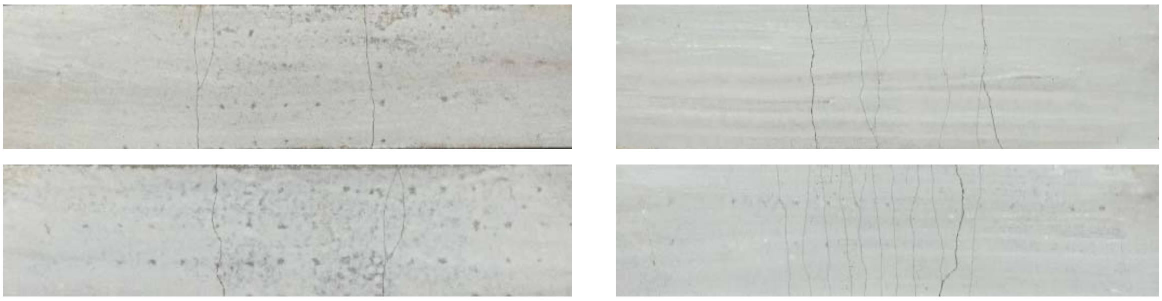
Figure 4: Typical four point bending curves for composites reinforced by 4% 25 and 50 mm length curaua fibers. Effect of length on flexural behaviour of composite.

Figure 5 presents the typical cracking patterns for composites reinforced with 2, 4% (R2%_25, R4%_25 – Figure 5a) and 6% (R6%_25 –Figure 5b) 25 mm curaua fibers. Composites R2%_25, R4%_25 presented only one cracking, while composite R6%_25 showed a mean of 3 cracks.

(a) (b)

Figure 5: Typical cracking patterns For: (a) R2%_25, R4%_25 composites, (b) R6%_25 composite.

The typical cracking patterns for composites reinforced with 2 and 4% of 50 mm curaua fibers composites (R2%_50, R4%_50) are shown in Figure 6. Composites reinforced with 2% fibers showed about two or three cracks (Figure 6a) and composite reinforced with 4% fibers presented a multiple cracking pattern with around nine cracks (Figure 6b). This behaviour shows that increasing the fiber volume fraction to 4% and the fiber length to 50 mm cracking bridges and cracking arrests are more effective resulting in a higher stress transfer from matrix to fiber. The multiple cracking process is extremely important, as it controls the toughness of cementitious composites. In fact, the R4%_50 composite presented the higher toughness.



(a) (b)

Figure 6: Typical cracking patterns For: (a) R2%_50 composite and (b) R4%_50 composite.

4 CONCLUSION

Based on the results obtained in the present work it can be concluded that the use of a cementitious matrix reinforced with curaua fibers, as reinforcement of cement composites, is a promising technique for developing sustainable materials to be applied in the civil construction industry.

Composites reinforced with 4% and 50 mm length curaua fibers presented a multiple cracking pattern with a post crack bending strength (PCS) of 4.59±0.58 MPa and with a toughness of 2.13±0.36 kJ/m^2. In fact, the use of short curaua fibers as reinforcement of cemente mortar can produce composites with appropriate mechanical properties allowing its use in semi-structural applications. It should be noticed that the composites used in this work were manufactured without any pressure. In further works, composites manufactured with a pressure of 3 MPa will be compared with the composites used in this work. The matrix might be optimized in order to obtained composites with higher PCS and toughness.

5 ACKNOWLEDGEMENTS

The authors would like to acknowledge the financial support given by CAPES and Faperj.

6 REFERENCES

[1] D'ALMEIDA, A.L.F.S., MELO FILHO, J.A., TOLEDO FILHO, R.D., "Mechanical properties of curauá fibers-cement based composites", *In: International Conference on Science and Technology of Composite Materials* (COMATCOMP 09), San Sebastian-Spain, pp. 831-834, 2009.

[2] D'ALMEIDA, A.L.F.S., MELO FILHO, J.A.; TOLEDO FILHO, R.D., "Use of curauá fibers as reinforcement in cement composites", *Mechanical & Chemical Engineering Transactions*, v. 17, pp. 1717-1722, 2009.

[3] TOLED, R.D, FAIRBAIN, E.M.R., MELO, J.A., SILVA, F.A., "Durability of compression molded sisal fiber reinforced mortar laminates", *Construction & Building Materials*, v. 23, 2008.

[4] SILVA, F.A., "Durabilidade e propriedades mecânicas de compósitos cimentícios reforçados por fibras de sisal", Tese de D.Sc., COPPE-UFRJ, Brasil, 2009.

[5] D'ALMEIDA, A.L.F.S, D'ALMEIDA, J.R.M, BARRETO, D.W., CALADO, V.M., "Flexural mechanical behavior of curaua fiber-reinforced composites: effect of mercerization and enzyme treatments", *In: Proceedings of the 4th International Conference on Science and Technology of Composite Materials*, COMAT 2007, RJ, CD-Rom, Paper_11 AP1, 09-12 de December, 2007.

[6] LEÃO, A.L., ROWELL, R., TAVARES, N., "Applications of natural fibers in automotive industry in Brazil-thermoforming process", *In: Science and Technology of Polymers and Advanced Materials-Emerging Technologies and Business Opportunities*, New York, 1998.

[7] ZAH, R., HISCHIER, R., LEÃO, A.L., BRAUN, I., "Curauá fibers in the automobile industry- a sustainability assessment", *Journal of Cleaner Production*, v.15, pp. 1032-1040, 2007.

[8] MELO FILHO, J.A., SILVA, F.A., TOLÊDO FILHO, R.D, FAIRBAIN, E.M.R., "Effect of Reinforcement Ratio and Molding pressure on The Mechanical performance of Short Sisal FRC.", In: PROCEEDINGS OF THE 4TH INTERNATIONAL CONFERENCE ON SCIENCE AND TECHNOLOGY OF COMPOSITE MATERIALS, COMAT 2007, RJ, CD-Rom, Paper_CS-01, 09-12 de December 2007.

[9] BENTUR, A., MINDESS, S., BETUR, A., MINDESS, S., *Fibre Reinforced Cementitious Composites* 2nd edition, Modern Concrete Technology, v. 15, pp. 108, 120, 2007.