CEMENT COMPOSITES REINFORCED WITH SHORT CURAUA FIBERS[1]

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Summary

The development of an eco-friendly material that can reduce CO_2 emission and aggregate value to a natural fiber setting man at the countryside and raising the income of populations from poor regions is a big challenge to the scientific community. In this particular, the lignocellulosic fibers can have an important role once they are a cheap and readily available reinforcement, requiring only a low degree of industrialization for their processing. The main drawback of using lignocellulosic fibers as reinforcement in cement composites is that they can be mineralized inside the alkaline pore water environment of the concrete. In this work, Portland cement was partially replaced by metakaolinite in order to produce a matrix free from calcium hydroxide, avoiding thus 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 indicated that multiple cracking cementitious composites can be obtained using short curaua fibers as reinforcement.

Keywords: Cement Composites; Vegetable Fibers; Mechanical Behavior

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1 INTRODUCTION

Nowadays there is an increasingly interest in the development of eco-friendly materials for the construction industry. Environmental challenges related to the necessity of reducing worldwide levels of CO_2 emissions and energy consumption are in the horizon and must be addressed by the scientific and industrial community. In this particular, special attention is being given to use of natural fibers as reinforcement of cementitious composites [1, 2, 3, 4,]. 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]. Curaua fibers have been used as reinforcement for polymer composites [5, 6], and are appraised as high strength lignocellulosic fibers [7]. However, not many publications are available about their use as reinforcement in cement based matrices. In this study cement mortar reinforced with 2, 4 and 6% of short (25 mm and 50 mm long) curaua fibers were manufactured and tested under four points bending load to determine the first crack, post-peak strength, toughness and fracture process of the composites.

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 50 mm length.

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

(a) (b)

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

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

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

Table 1. Nomenclature of the manufactured composites

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 midspan displacement of 15 mm.

3 RESULTS AND DISCUSSIONS

The results obtained from the four point bending tests (mean ± standard derivation - SD), with the respective coefficient of variation (CV, expressed in %) are presented in Table 2. The effect of curaua volume fraction ratio and fiber length on the load-deflection curves can be observed in Figures 2, 3 and 4.

Composites	FCS±SD (MPa) (CV%)	δ (FCS) ±SD (mm) (CV%)	PCS±SD (MPa) (CV%)	Toughness±SD (kJ/m²) (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)

Table 2. Summary of the Four Point Bending Test results

Observing the presented results it can be noticed that the FCS values decreases from 6.59 ± 0.48 MPa (R2%_25 composite) to 4.45 ± 0.46 MPa (R6%_25 composite) with the increase in the fiber volume fraction from 2% to 6%. This happen because is more difficult to disperse elevated volume fractions of curaua fibers in the matrix [1, 8, 9]. A similar behavior was observed when the longer fibers (50mm length) were added to the matrix. In this case the FCS values of the composite R2%_25 was reduced from 6.59 ± 0.48 MPa to 4.77±0.41 MPa. The increase in fiber length (for the same volume fraction) introduced a bit more of damage in the matrix due to the higher difficulty in the dispersion of the longer fiber.
Regarding to the post-cracking strength behavior, it can be observed that for composites reinforced with 25 mm long fibers there is an increase of about 50% and 61%, respectively, when the volume fraction is increased from 2% to 4% and from 2% to 6%. For the composites reinforced with 50 mm fiber length, an increase of about 43% was observed when the volume fraction of fibers was increased from 2 to 4%.
In relation to the influence of the fiber length on the post-cracking composite behaviour, it can also be observed that higher PCS values are obtained for the mixes reinforced with 50mm long fibers. For example, an increase of about 85% was observed for the PCS value of composite R2%_50 when compared with the PCS value of the composite R2%_25. For the mixtures reinforced with 4% of curaua fibers (R4% composites) the increase in the PCS value was less expressive but still quite high (increase of about 33 % in the PCS value).
Observing the curves of equivalent flexural stress versus displacement (Figures 2, 3 and 4), and the values of PCS presented in table 2 it can be concluded that the critical volume (V_c) in bending for the curaua fiber cement mortar composites is higher than 6% for the fiber length of 25mm (Figure 2). In this analyze the critical volume is defined as the fiber volume fraction that leads to a post-cracking bending stress equal to its first crack strength (see eq 1) [9]. Observing the results presented in Figure 3 and Table 2 for the composite R4%_50 it can be seen that the PCS value was slightly higher than the FCS value. Therefore, the critical volume fraction for the 50mm long composite is about 4%.

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

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

Regarding to the flexural toughness behavior of the composites, it can be observed that for composites reinforced with 25 mm long fibers there is an increase of about 36% and 51%, respectively, when the volume fraction is increased from 2% to 4% and from 2% to 6%. For the composites reinforced with 50 mm fiber length, an increase of about 35% was observed when the volume fraction of fibers was increased from 2 to 4%.

In relation to the influence of the fiber length on the toughness composite behaviour, it can also be observed that higher PCS values are obtained for the mixes reinforced with 50mm long fibers. For example, an increase of about 50% was observed for the toughness value of composite R2%_50 when compared with the flexural value of the composite R2%_25. For the mixtures reinforced with 4% of curaua fibers (R4% composites) the increase in the toughness value reached about 34%.

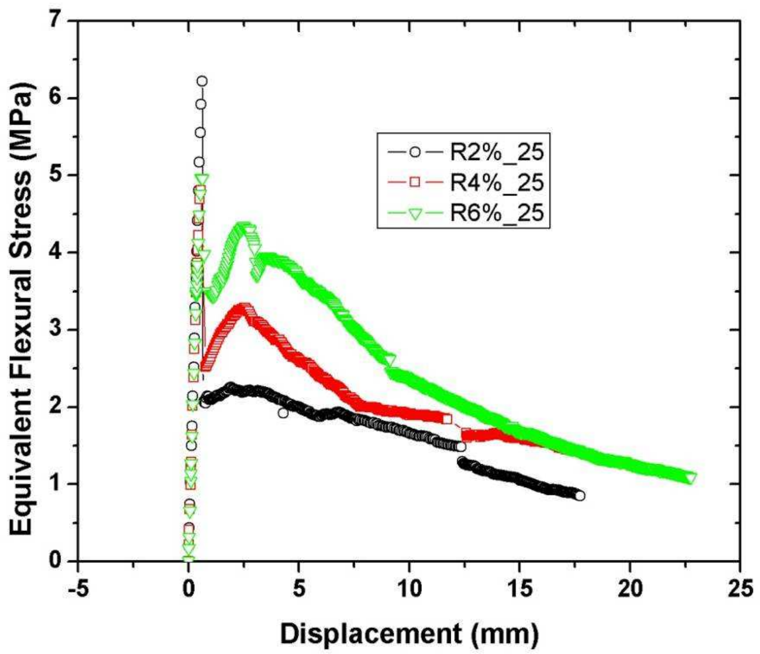

Figure 2. Typical four point bending curves for the composites reinforced with 2%, 4% and 6% of 25 mm long curaua fibers.

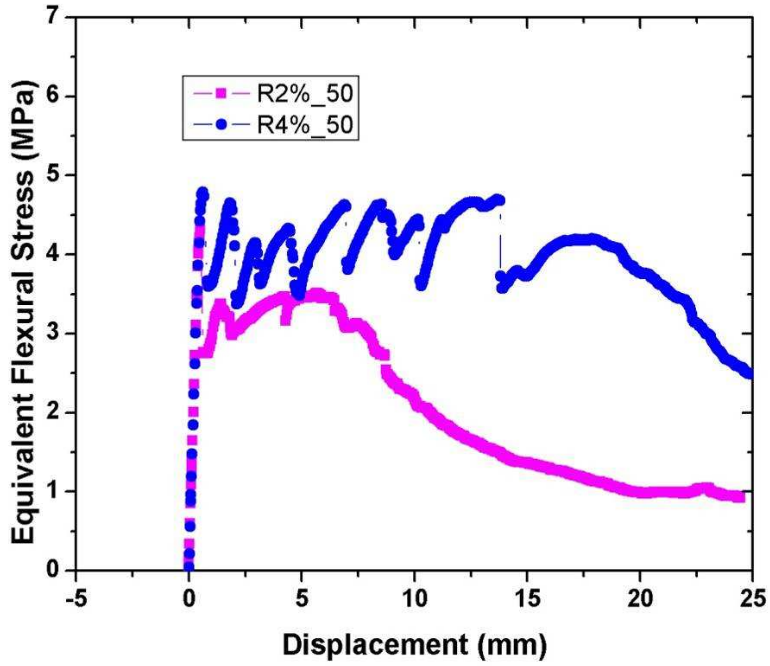

Figure 3. Typical four point bending curves for the composites reinforced with 2% and 4% of 50 mm long curaua fibers.

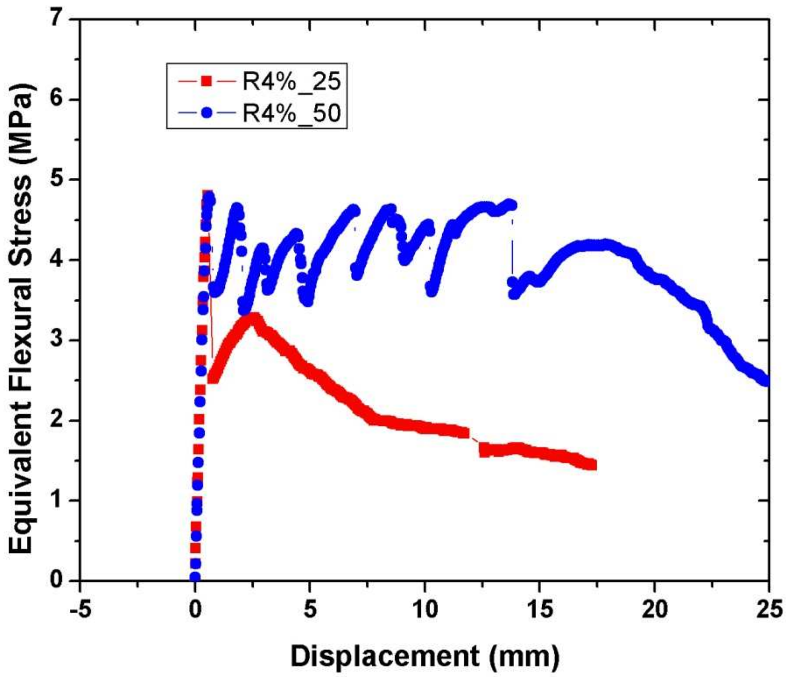

Figure 4. Typical four point bending curves for composites reinforced with 4% of curaua fibers: effect of length on flexural behaviour of composite.

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

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Figure 5 shows the typical cracking patterns in the bending zone (300mm span) for the composites R2%_25, R4%_25 and R6%_25. It is observed that the specimens reinforced with 2% and 4% of 25mm long curaua fibers presented a single cracking behavior under bending loads. The number of cracks increased, however, for the mixture reinforced with 6% of fiber. In this case the crack number ranged from 2 to 5 cracks.

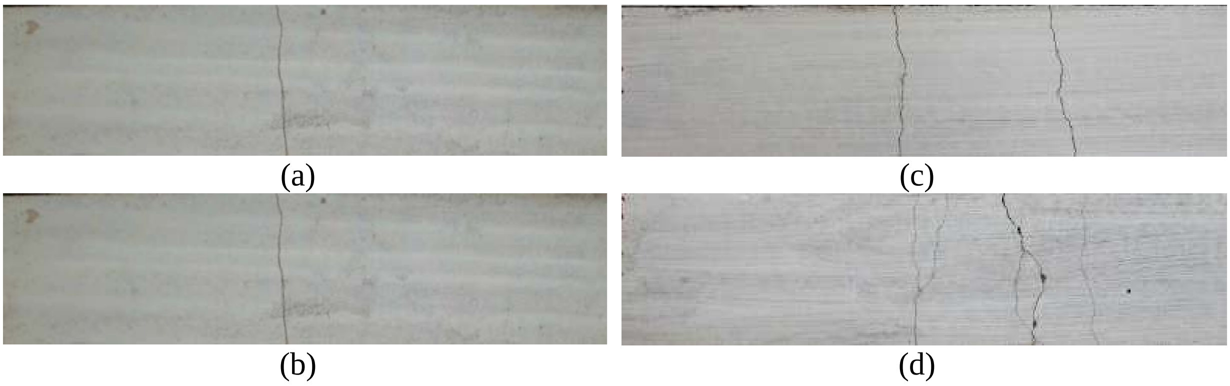

Figure 5. Typical cracking patterns for the composites (a) R2%_25, (b) R4%_25, (c) and (d) R6%_25.

The typical cracking patterns for the composites reinforced with 2 and 4% of 50 mm long curaua fibers (mixes R2%_50 and R4%_50) are shown in Figure 6. Composites reinforced with a volume fraction of 2% presented about three cracks (Figure 6a) whereas the composite reinforced with 4% fibers presented a multiple cracking pattern with a number of cracks ranging from 7-12 cracks (Figure 6b). This multiple cracking process is extremely important for the composite performance once it controls the toughness and durability of cementitious composites.

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

4. CONCLUSION

Short curaua fiber-cement mortar composites (CFCMC) with multiple cracking behavior under bending loads were developed in this study. The best performance was obtained for the mixture reinforced with a fiber volume fraction of 4% and fiber 50mm long. In this case post crack bending strength of about 4.6 MPa was reached with a bending toughness calculated up to a deflection of 15mm of about 2.2 kJ/m^2. The failure of this composite under bending occurred after a mid-span deflection of about 15 mm. After this stage the composite presented a strain softening response due to the localization and widening of one of the existing cracks. The mixes reinforced with 25mm long fibers presented single cracking fracture up to a volume fraction of 4%. The mixture reinforced with 6% of 25 mm long fiber and the mixture reinforced with 2% of 50mm long curaua fiber presented an intermediate behavior with a number of cracks ranging between 3 and 4 and mid-span deflection before localization ranging from 3-6mm. The results presented in this work demonstrated the high potentiality of the use of short curaua fiber as reinforcement in cement based composites for semi-structural and structural applications.

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