The Use of Strain Hardening Natural Fabric Reinforced Cement Based Composite Systems for Structural Applications

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Abstract. It is known that the use of natural fibers as reinforcement for composite materials present economic benefits and eco-friendly appeal when compared to man-made fibers. However, even demonstrating excellent mechanical performance due to the strain-hardening behavior, its use for structural applications still presents a gap in the literature. Therefore, the current work discusses the use of natural fiber cement-based composites as external strengthening for concrete structures. For such, curauá natural fibers were used as reinforcement in a cement composite, which was used as a strengthening material for RC structural beams. The beams were strengthened for flexural and shear. Both externally reinforced specimens presented an increase in loading capacity and deflection decrease compared to their respective references, which was associated with a yielding delay on the rebars in a range between 21% to 34%.

Keywords: Natural fibers · Cement-based composites · Structural applications

1 Introduction

The use of natural fibers as reinforcement in cement matrices has a solid economic and ecological appeal for the new directions of the construction industry. Mechanically, many authors [1–9] described the excellent performance of that kind of composite material, mentioning increases in strength and strain capacity after the first crack due to the multiple-cracking ability. Souza et al. [10] studied cement composites reinforced by curauá long fibers in volume fractions of 4%, 7%, 8%, reaching tensile strength up to 14.7 MPa with a strain capacity of 1.6%. d'Almeida et al. [11] also studied cement composites reinforced by curauá long fibers but under bending testes, which presented flexural hardening behavior with a strength of 27.5 MPa.

However, even showing exceptional mechanical potential, natural fiber composite applications are still limited to elements such as tiles [12–14], paving blocks [15, 16], or non-structural masonry [17–19], while structural applications are commonly associated to man-made fibers, mainly polymeric and steel. As example, Lima et al. [20] evaluated short sisal fiber reinforced concrete (SSFRC) block for one-way precast concrete slabs,

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and its behavior under the bending test presented a typical flexural hardening. Compared to the commercial blocks (ceramic and EPS), the SSFRC showed more than twice their resistance and non-brittle failure mode, reaching a load capacity 157% higher than the minimum load required by the standard for these types of blocks.

Therefore, to fill this gap, this work presents the use of a cement-based composite reinforced by natural curauá fibers as a strengthening system for RC beams. The composite was externally applied on the surface of the beams, focusing on improving the resistance to shear and bending moments. The beam submitted under flexural tests had its bottom side covered by the composite material, while for shear tests, the composite was applied over the specimen on both lateral sides. For comparison, reference beams were performed during the load tests.

2 Materials and Methods

The curauá fibers were firstly treated with hot water (70 ± 3 °C) for one hour, aiming to eliminate the impurities retained on the fiber surface [21]. Under mechanical tests, the curauá fibers presented a tensile stress equal to 706 MPa at a strain-to-failure of 2.4% with Young's modulus of 32 GPa, as presented by Teixeira et al. [22]. The composite cement matrix was designed for a 1:1:0.4 ratio (cementitious material, quartz sand and water). The cementitious material was composed in mass by 50% of Portland cement type CPV [23], 40% of metakaolin and 10% of fly ash; these pozzolans supplementation aims to produce a calcium hydroxide free matrix [21]. The matrix presented an axial compressive strength equal to 81.0 MPa after 28 days. The composite manufacturing consists of a layering process, in which a matrix layer was placed in a steel mold followed by a layer of curauá fibers, one later at a time. The curauá fibers amount per specimen corresponds to a volume fraction of 5%, divided into three layers longitudinally oriented. This process resulted in composite laminate plates measuring 500 mm length, 60 mm width, and 10 mm thickness. These specimens presented strain-hardening behavior under tensile tests, reaching maximum stress equal to 12.8 MPa at a strain-to-failure of 2.7% with Young‘s modulus of 4.7 GPa, as described by Teixeira e Silva [24].

The concrete mix for structural RC beams is explained in Table 1, and its average axial compressive strength after 28 days reached 33 MPa. The structural beams were designed with a flexural reinforcement ratio of 0.55% (two 8 mm bars), with two distinctions: 1) the beams designed for flexural failure presented shear reinforcement stirrups with 125 mm spacing while 2) the beams designed for shear failure presented no shear reinforcement along the testing region. For the conventional reinforcement, steel rebars with the nominal yield strength of 500 MPa were used, and the beam was cured for 14 days before the composite application. Figure 1 presents the schematic beam details and dimensions.

For the composite application as external strenghening layer, 10 mm thick laminate plates were manufactured over the beams‘ surfaces. The composite plates were fabricated with three curauá fiber layers (volume fraction of 5%). For the external flexural strengthening layer, the composite was applied at the bottom of the beams, while for the shear the application was at both lateral sides. To achieve the desired length, fibers overlaps of 70 mm were adopted for continuity. The tests on structural beams were carried in an MTS servo-hydraulic system (500 kN load capacity) with deflection values acquired

Table 1. Concrete mix proportions.

Materials	Kg/m^3
Portland cement (CPII-F32)	336.0
Natural sand	642.0
Coarse aggregate (9 mm)	441.0
Coarse aggregate (19 mm)	782.0
Water	168.0
Superplasticizer (PLASTOL® 4100)	0.5

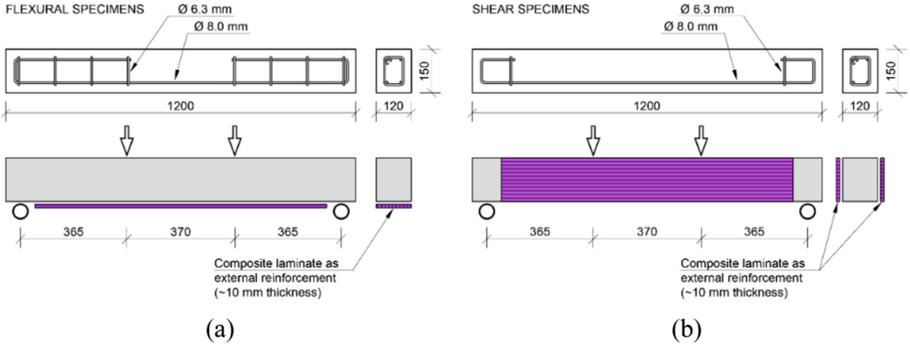


Fig. 1. Schematics of beams details and dimensions: flexural specimens (a) and shear specimens (b).

by three LVDTs arranged at the beam's bottom, aligned with the load points and at its center part. The strain measurements were read by strain gauges on the steel rebars, placed on each rebar. The test displacement rate was 1.0 mm/min over an 1100 mm span between end supports.

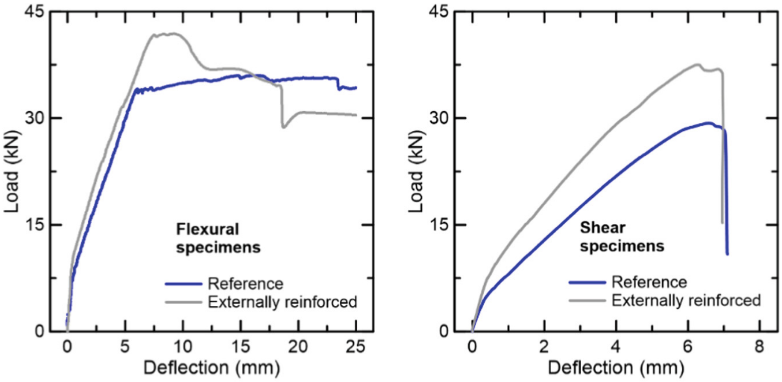
3 Results and Discussions

Both structural beams strengthened for flexural and shear presented an increase in loading capacity and a decrease in deflection range compared to their respective references. The flexural reference specimen presented a load peak of 36.0 kN, while its externally reinforced counterpart showed a maximum load capacity of 41.9 kN (16% higher). The same occurred to the shear specimens, which the externally reinforced beam demonstrated a strengthening increase of 28% over its reference (37.5 kN over 29.3 kN, respectively), as well as a higher stiffness. Figure 2 show the failure of both externally reinforced beams and Fig. 3 present the mechanical behavior of flexural and shear specimens.

About the deflection at maximum load, the shear specimens presented a reasonable variation, in which the externally reinforced beam exhibited a decrease of 4.5% compared to its reference (6.6 mm to 6.3 mm). On the other hand, the deflection decrease

(a) (b)

Fig. 2. The externally reinforced beams: flexural failure (a) and the shear failure (b).

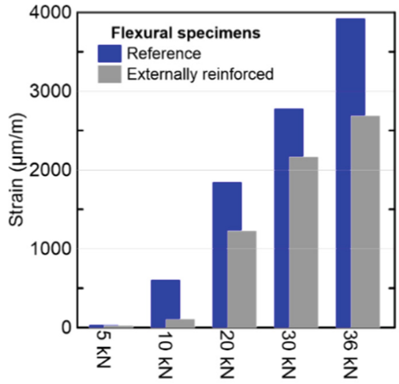


(a) (b)

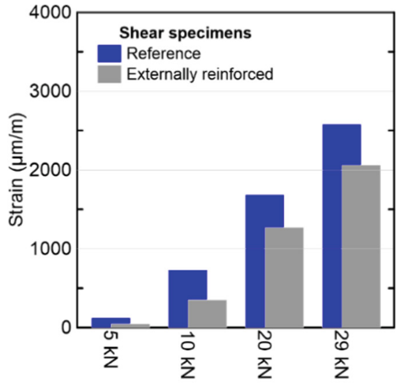
Fig. 3. Mechanical behavior of specimens under flexural tests (a) and shear tests (b).

demonstrated by the externally reinforced beam under the flexural test was expressive, reaching 43.2% (16.2 mm of the reference beam against 9.2 mm of its externally reinforced counterpart). The same load capacity increase with deflection decrease was presented by Schladitz et al. [25] in textile high-performance carbon-composite as concrete slabs reinforcement. It is possible to assume that these decreases in deflection range are associated with a yielding delay on the rebars caused by the composite strengthening contributions, resulting in stiffness gains. Figure 3 shows a comparison of the rebars yielding progress (measured by the strain gauges) at different loading stages up to the maximum strength of each reference specimen, under flexural and shear tests (Fig. 4).

In general, the reference specimens showed higher rebar strains at all known loads, from 5 kN up to each respective maximum strength, which indicates a relevant contribution of the longitudinal continuous curauá fibers to resist the forces at the tension zone. The strain measurements on the rebars were reduced 34% for the flexural reinforced specimen and 21% for the shear reinforced one, compared to their respective references at its maximum loading. It is worth mentioning that, even different from usual



(a)



(b)

Fig. 4. Correlation between rebars yielding progress and load capacity: flexural specimens (a) and shear specimens (b).

wrapping techniques or transverse external reinforcements, the proposed shear strengthening system (sideways applied over almost the total length of the beam) also had a valuable contribution to flexural resistance and stiffness. Furthermore, in both cases the longitudinal rebars did not reach their nominal yielding at failure.

4 Conclusions

The developed natural curauá fiber-reinforced composite demonstrated an excellent behavior as a structural component, providing a higher load and strain capacity to the externally strengthened RC beam. The following are some highlights of present work:

- The natural fiber composite as a structural reinforcement provided an increase in the ultimate strength of the structural beams before its maximum deflection, about 16% and 28% for flexural and shear specimens, respectively;
- The adopted application method proved to be effective, presenting no signs of failure due to delamination or displacement, providing stiffness enhancement to the beams;
- The stiffness increase and deflection decrease can be associated with the yielding delay on the rebars caused by the composite strengthening contributions.

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