Application of natural fiber composite materials in the strengthening of reinforced concrete structures

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Abstract. This paper presents an experimental investigation of strengthened reinforced concrete structure by bonded natural fiber composite materials. Nonetheless, the composite plates are externally constituted of a matrix based on epoxy adhesive in which the aligned continuous natural fibers are embedded. In recent years, the natural fibers are of great interest as a result of policies to reduce the negative impact on the environment. They are a renewable source, helping to capture carbon dioxide during their cultivation. Numerous technical, economic, and environmental advantages such as low cost, high strength-to-weight ratio, low density, and non-corrosive properties make them very attractive to use. The objective of this research is to assess the strengthened capacity of natural fibers. This research mainly used hemp and flax natural fibers. So, these natural fibers are an alternative to synthetic reinforcing fibers like carbon fiber or glass fiber, which are widely used in civil engineering. This article briefly presents the results of the tests carried out on concrete prismatic specimens strengthened by external bonding different composite plates based on natural fibers. The tests were presented by examining the influence of reinforcement on the ultimate capacity and the element of rigidity. The results show a significant increase in the ultimate load of the strengthened concrete prismatic specimens compared to the reference specimen. The cracking and failure modes are presented. The results show that the natural fibers are a good alternative to glass and carbon fibers.

1. Introduction
Over the last decade increases scientific research of the natural plant fibers owing to environmental issues on global warming and in the term of environment protection. They are a renewable source, helping to capture carbon dioxide during their cultivation and their using allows for reducing environmental impact. Biomaterials are mainly used in many sectors of human activities such as in construction sector (building, flooring, sound insulation bricks...), and in the cars industry sector, which requires light materials with best performance. These materials have a potential for recycling and natural degradation, which contributes to the minimum impact on the environment. The natural composite materials are constituted of a matrix based on epoxy adhesive and aligned continuous plant fiber reinforcements having a structural function presents interesting mechanical properties. Numerous technical, economic, and environmental advantages such as low cost, high strength-to-weight ratio, low density, and non-corrosive properties make them very attractive to use [1-2].
The widely used composite carbon fiber plates in civil engineering, has become a real alternative in the field of rehabilitation of structures, but they have drawbacks such as high costs during the manufacturing and end-life services, cause adverse effects to human health and less environmental-friendly.

The technique of the strengthening of concrete structure has begun with bonding steel plates [3], then the appearance of synthetic Fiber Reinforced Polymer (FRP) composites [4-5] consists of bonding a composite plate on the beam underside bending reinforcement [6], or the side areas flexural and shear reinforcement [8-12], or prestressing reinforcement [7]. This technique enables us to make structures safe and suitable in service when the environment changed to improve the durability of the structures. The advantages of this strengthening technique are: better distribution of stresses in the adhesive layer compared with tightening or welding technique, easy and speed handling, the work can be carried out during construction sites.

Scientific research is being carried out to replace the most common composites (e.g. carbon and glass fibers) by materials less harmful to the environment, as natural fibers in the field of civil structures. The natural composite materials by plant fibers such as jute, flax, sisal, cotton, bamboo, hemp, coconut fibers are studied [13-17]. Therefore, these fibers have interesting physical and mechanical properties. This technique of reinforcement allows to increase remarkably the bending and shear stresses of the structures and in addition to new stresses.

The objective of this study is to investigate the possibility of reinforcing structures using natural biobased fibers. Hemp and flax natural fibers were used in this case. These natural fibers are an alternative to synthetic reinforcing fibers like carbon fibers or glass fibers, which are widely used in civil engineering. The results of the tests carried out on prismatic concrete specimens strengthened by external bonding different composite plates based on natural fibers are presented. The results show that the natural fibers are a good alternative to glass fibers.

2. Materials

The natural reinforced fiber composites are attracting increasing attention because of their low cost, low density, biodegradability and availability, ease of processing, high specific modulus, and their capacity to be recycled, minimum impact on the environment, and a reduction in their cost. The natural fibers are hydrophilic because they are composed of lignocellulose, which contains hydroxyl groups. They are therefore incompatible with hydrophobic thermoplastics such as polyolefins and have a low resistance to moisture. This weak point has improved a matrix of polymer type in order to highlight their mechanical properties (Table 1).

| Material         | Young’s modulus [GPa] | Strength [MPa] | Poisson ratio |
|------------------|------------------------|----------------|--------------|
| Concrete         | 30                     | 35             | 0.25         |
| Adhesive         | 11                     | 24             | 0.40         |
| Flax FCP         | 62                     | 22             |              |
| Hemp2.5x2.5 FCP  | 60                     | 21             |              |
| Hemp3x3 FCP      | 63                     | 24             |              |
| Glass FCP        | 70                     | 31             |              |
| UCFCP*           | 90                     | 1055           | 0.45         |

*UCFCP: Unidirectional Carbon Fiber Composite Plate.

The normal concrete was used for all specimens. The cement:sand:gravel proportions in the concrete mix were 1:1.7:2.9 by weight. The water/cement ratio was 0.5 and cement type II Portland was used. The maximum size of the aggregate was 16 mm. Four 160 mm x 320 mm concrete cylinders were cast and tested to determine the mechanical proprieties of the concrete. The average compressive strength was 35 MPa and the flexural tensile strength was 4.5 MPa. The concrete had an average elastic modulus of 30 GPa. A summary of the mechanical properties of the “Sikadur 30” adhesive is given as Young’s Modulus of 11000 MPa, the tensile stress of 24 MPa, and Poisson ration of 0.40. Fiber fabrics of hemp, flax, glass, and carbon have been tested. Figure 1 shows the natural fiber fabrics used with different
One bidirectional flax fiber fabric (Fig. 1a) and two bidirectional hemp fiber fabrics (Fig. 1b and 1c) with a similar quality were tested to show the difference between them. The results showed a good penetration of resin in composite plate manufacture. Figure 2 shows the synthetic reinforcing fiber fabrics (bidirectional glass fiber fabric (Fig. 2a) and unidirectional carbon fiber fabric (Fig. 2b)).

3. Experimental setup

3.1. Influence of different types of fiber fabrics

Five types of materials of Figures 1 and 2 were tested. For each type of fiber, four to eight specimens are stressed in tension. First the fabrics were tested and secondly, the composite plates (adhesive and fiber) were made and tested as well.

3.2. Influence of different composite plates

The composite plates were prepared manually with one layer of fabric and bonded together with an epoxy matrix, then they were pressed. The lay-up normally cures at room temperature for 24 hours. Pull off tests were carried out, with a tensile machine at constant speed of 0.25 mm/s, until sample collapses (Fig. 3a). The extensometer technique based on electrical strain gauges was used to study the local behavior. This technique contributes to measure the strain of composite fabrics (Fig. 3a) and concrete in specific point of the structure. In fact, the strains are measured using strain gauges bonded to the composite fabric sheets in the middle of the specimens where the bending moment is maximum.

The bonded area of both the composite plate, need a special preparation to carries out to remove all weak material, oil, grease, etc. The concrete was sand-blasted down to the level of the aggregate and was cleaned by using a water jet to ensure a good bond between the epoxy glue and the concrete surface. The resin and hardened were just hand-mixed and hand-applied on the concrete surface. The glue has hardened for 24 hours. The adhesive thickness was 1 mm. The composite fibers were adhered to the lower area of the reinforced concrete structures by using an epoxy resin (Fig. 3c). It allows for increasing the bending and shear stresses of the structures. Of course, this approach also contributes to the durability of civil engineering structures and at the same time it using a strengthening system with environment respect.
In this series, five prismatic concrete specimens (100 mm by 100 mm by 400 mm) were strengthened with epoxy-bonded fiber composite plates, and one without strengthening - control specimen. The specimens were instrumented with electrical gauges and the displacement captor LVDT, Figure 3b. All concrete specimens were tested under a four-point load. So, this last device allows one domain where shear strengths are null. For each test, mid deflection, concrete strain distribution, strain of the composite plate, and the cracking state were noted. The evolution of the neutral axis position was determined by the deformation of strain gauges on the central section of the specimen. During the tests, load strain and deflection were recorded by an automatic data acquisition system.

4. Results and discussion
Figure 4 shows the experimental results obtained for composite materials. We usefully compare the result of fiber fabrics and composite plates.
Figure 5 shows the comparison between natural fiber composites plates and Glass FCP in tensile test. Composites reinforced with natural fibers have a tensile behavior similar to that reinforced with glass fibers. The composite materials plates have a linear elastic behavior up to failure.

![Stress versus strain of fiber fabrics and adhesive in tensile tests](image)

**Figure 5.** Stress versus strain of fiber fabrics and adhesive in tensile tests

The results in Table 2 show the effect of strengthening. The results show that the flexural properties of flax FCP for strengthening was similar to Glass FCP. Contrariwise the hemp flexural properties were lower.

|                  | Control specimen | Hemp 3x3 FCP | Flax FCP | Carbon UCFCP | Glass FCP |
|------------------|------------------|--------------|----------|--------------|-----------|
| Ultimate load $F_u$ [kN] | 12,09            | 13,02        | 15,74    | 23,50        | 15,72     |
| $F_u/F_0$ [%]     | 0                | 8            | 30       | 94           | 30        |
| Displacement [mm] | 5,23             | 8,84         | 4,83     | 7            | 8,76      |

5. **Conclusion and perspectives**

In this paper, the mechanical properties of reinforced natural plant fiber epoxy composites have been described. The tensile, flexural and hardness properties of reinforced natural fiber polymer composites show a significant improving (positive effect) on strengthened concrete specimens. The results present:

- The bio-based materials such as hemp and flax fibers can contribute to a reinforcement of a concrete beam from 1% to 30%.
- In comparison to bidirectional glass fiber fabric, the natural fiber fabrics (flax and hemp) are a good alternative to glass fibers.
- The tests carried out concern a single layer of hemp and flax fibers, in fact, it would be interesting to carry out other studies in order to determine the optimum thickness for effective reinforcement on reinforced concrete beam.

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