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Investigation of the bond behavior of flax FRP strengthened RC structures through double lap shear testing

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ABSTRACT

This paper focuses on the characterization of the bond behavior of adhesively bonded Flax Fiber Reinforced polymers (FRP) to concrete substrate. An experimental investigation has been done comparing flax and glass FRP bonded to concrete using a double shear test configuration. Flax composites appear to show the same interface behavior as the usual synthetic fiber reinforcement. Analyses of the strain and shear stress distribution along the interface reveal behavior differences.

To investigate if the same models could be accurately used in the case of flax FRP or if a new model is needed, experimental results of debonding load and efficient bonded length have been compared to the values of four different prediction models. Coefficients calibrated for the flax composite lead to an underestimation of the efficient bonded length for the glass composite.

1. Introduction

The strengthening through external bonding of Fibers Reinforced Polymers (FRP) using glass, carbon or other fibers has been extensively developed in the last 20 years and proven effective for the reinforcement and retrofitting of concrete structures. Intensive research has been carried out on the bond behavior between composite and concrete (e.g. Abdel Baky et al. [1], Chajes et al. [2], Ferrier et al. [3,4], Yuan et al. [5], Yao et al. [6] …). It is meant to offer better design methods and therefore open the field to new reinforcing configurations and materials. The strategy in reinforcement design usually promotes high strength and stiffness over high deformability. It is however worth reconsidering those assumptions since strength and stiffness can be replaced using a bigger cross section of a material with lower properties, which is not the case for deformability. Especially in shear strengthening, fibers with large fracture strain and without yielding give ductile shear failure. Natural fibers are inexpensive, light weight and eco-friendly, and present rather large fracture strain. Flax fibers are as stiff/strong as glass or organic fibers such as PET. With the increasing environmental concern, the use of natural fibers in the construction industry can help achieve lower environmental impact. A few attempts to use natural fibers like jute or flax concluded positive for the use to repair or retrofit concrete structures (e.g. Yan et al. [7], Kwiecień et al. [8], Sen et al. [9]). It remains however necessary to have a better understanding of the bond behavior with those new potential reinforcement materials as to insure their efficient and secure use in the construction industry.

This study aims to assess the effectiveness of flax FRP composites as external strengthening materials for concrete structures. In this paper, an investigation of the bond behavior between the concrete surface and flax FRP manufactured with wet lay-up process is introduced. Mechanical tests were conducted by double lap shear loading on flax and glass FRP-strengthened RC specimens with different configurations. The experimental data was analyzed through average and local shear stress/slip curves. The results were then compared to the theoretical values of different bond strength prediction models.

2. Experimental investigation

2.1. Double lap shear test description

Although single lap shear tests are more widely exploited in literature, the interface can rapidly be subjected to normal and bending stresses in addition to the shear stresses. This artefact can influence the failure mode and induce earlier failure (e.g. Abdel Baky et al. [1], Hadigheh et al. [10], Chajes et al. [2]). In contrast, double lap shear tests appear to have more consistent and comparable responses. The standard double lap shear test proposed by

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the Japanese Concrete Institute and modified by Ferrier (1999) was retained for this investigation. This test configuration has been operating for many studies in the laboratory in recent years (e.g. Marouani [11], Michel [12], Mead et al. [13], Ferrier et al. [2,3], Ferrier [14]) which offers possibilities of essential comparisons.

The double lap shear test configuration illustrated in Fig. 1 consists of two concrete blocks internally reinforced by a threaded rod and bonded by two parallel bonded FRP strips. A tensile load is applied to the concrete blocks inducing the transfer of shear stress to the adhesive joint without any flexure until failure of the system. The tests were performed on a universal tensile machine Zwick 1475 at a cross-head speed of 1 mm/min until failure of the specimens at room temperature (20 °C).

2.2. Materials and preparation of the specimens

The two concrete blocks (14 cm × 14 cm × 25 cm) were prepared according to NF EN 18–422 with ready-to-mix commercial mixture with a 28-day compressive strength of 35 MPa, corresponding to a tensile strength of 2.2 MPa (see Table 1).

The flax fabrics used in this study were grown and produced in north of France following the quality and traceability NF XP T 25–501 norms specific to technical flax fibers. They went through the four usual stages of preparation: pulling, retting, scutching, and heckling into ribbons. The quality of the final ribbon is standardized by mixing fibers from different productions years and flax varieties. The unidirectional fabrics are holding together by fine weft yarns and the bidirectional fabrics are woven in 3/3 twill offering balanced properties in both 0/90° directions. The glass fabric has a balanced bidirectional plain weave. Table 2 specifies the characteristics of the fabrics used in this study.

The composite strips are bonded symmetrically on opposite sides of the blocks with a bonded length of 200 mm on each block. The fiber orientation was 0° along the longitudinal direction of the tensile stress. The composite strips are manufactures through wet lay-up process. Two bi-components epoxy resins curing at ambient temperature and commonly used in concrete strengthening have been selected. The fibers were impregnated with a low viscosity epoxy A and layered on a more viscous compatible epoxy resin B, enabling the composite to stick to the concrete surface. The epoxy and hardeners have been mixed at the specified ratio 33:17 for A and 7:3 for B. Excessive resin and air bubbles are scraped out and

Table 1
Composition of the concrete mixture.

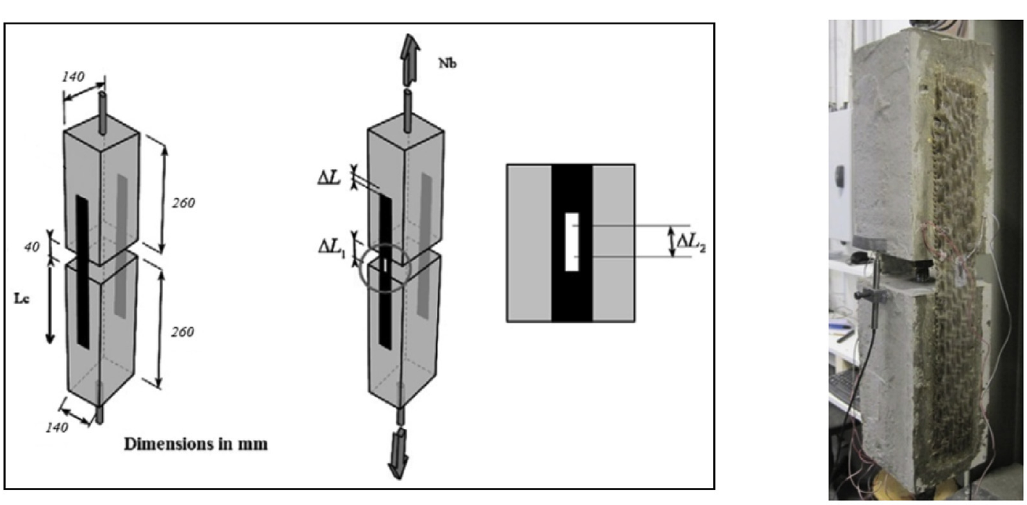
Material	Cement CEM I	Sand 0/5	Gravel 10/25	Water
Quantity (kg/m^3)	350	850	1020	192

the composites are left to cure at ambient conditions (20 °C/50% RH) during at least 1 month. Table 3 specifies the characteristics of both the epoxy resins used in this study. Three different composites were manufactured, using two different flax fiber fabrics and one glass fiber fabrics. Three specimens have been testes at least for each set. Table 4 indicates the characteristics of the different sets of reinforced concrete.

The composite have been characterized through tensile test in the fibers main direction on a universal tensile machine Zwick 1475 at a cross-head speed of 1 mm/min until failure of the specimens at room temperature (20 °C) (see Fig. 2). The ultimate strain and tensile modulus of the composites were calculated using the net fiber area, i.e. the area of the fibers neglecting the resin, as introduced by the American Concrete Institute for the hand-laid composites. The tensile stress per composites width was also calculated (ξ_u) in kN.cm^{-1}. For the flax FRP the stress-strain curves present a higher slope at small deformations as has been previously stated by many with flax fibers (e.g. Baley et al. [15], Poilâne et al. [16]). Scida et al. [17] have associated this phenomenon by the reorientation of flax micro-fibrils. Two modulus were therefore calculated for the flax composites following Bensadoun et al. [18] recommendations, a first E_1 between 0 and 0.1% strain, and a second E_2 between 0.3 and 0.5% strain. The modulus for the glass composite was calculated following the ISO 527-1 norm, between 0.05 and 0.25% strain.

2.3. Instrumentation and calculations

The calculations were done following the recommendations of the AFGC [19]. Strain gauges of resistance 120 Ω on the surface of the FFRP enable to measure its deformation the central part of each strip and along the central axis of one of them. Two LVDT displacement sensors (10–4 mm precision) measure the distance between the blocs at each sides of the interval (ΔL_1). The increase of this distance is due to the composite elongation (ΔL_2) and the slip



(a) Test principle of the double lap shear test (b) Photography of a test.

Fig. 1. Double lap shear test configuration.