Composites: Part B 69 (2015) 256–266

Contents lists available at ScienceDirect

Composites: Part B

journal homepage: www.elsevier.com/locate/compositesb

Effects of fabric parameters on the tensile behaviour of sustainable cementitious composites

O.A. Cevallos [a,b,*], R.S. Olivito [a]

[a] Dipartimento Ingegneria Civile, Università della Calabria, Rende (CS) 87036, Italy
[b] Facultad de Ingeniería, Universidad Nacional de Chimborazo, Riobamba 060150, Ecuador

ARTICLE INFO

Article history:
Received 26 June 2014
Received in revised form 31 August 2014
Accepted 2 October 2014
Available online 13 October 2014

Keywords:
A. Fabrics/textiles
B. Mechanical properties
D. Mechanical testing

ABSTRACT

The mechanical behaviour of fabric-reinforced composites can be affected by several parameters, such as the properties of fabrics and matrix, the fibre content, the bond interphase and the anchorage ability of fabrics. In this study, the effects of the fibre type, the fabric geometry, the physical and mechanical properties of fabrics and the volume fraction of fibres on the tensile stress–strain response and crack propagation of cementitious composites reinforced with natural fabrics were studied. To further examine the properties of the fibres, mineral fibres (glass) were also used to study the tensile behaviour of glass fabric-reinforced composites and contrast the results with those obtained for the natural fabric-reinforced composites. Composite samples were manufactured by the hand lay-up moulding technique using one, two and three layers of flax and sisal fabric strips and a natural hydraulic lime (NHL) grouting mix. Considering fabric geometry and physical properties such as the mass per unit area and the linear density, the flax fabric provided better anchorage development than the sisal and glass fabrics in the cement-based composites. The fabric geometry and the volume fraction of fibres were the parameters that had the greatest effects on the tensile behaviour of these composite systems.

1. Introduction

Due to the growing global demand for new materials produced with low energy consumption that offer sustainability, recyclability and particularly good mechanical properties, composites reinforced with natural fibres have attracted the interest of scientists over the past two decades. These fibres are a renewable resource and are available almost all over the world [1]. Composites reinforced with natural fibres, also known as bio-composites or green composites, have the potential to serve as next-generation materials for many applications [2–4]. To date, the most popular composite materials used to perform repair and strengthening operations have been fibre reinforced polymer (FRP) composites [5–7]. However, some drawbacks related to the use of polymeric resins are manifested in the use of FRP composites; indeed, both mechanical issues and incompatibility with the substrate material have been documented [8–10].

Using an inorganic matrix such as cement favours the effective bonding between reinforcing fibres and the matrix and also between the composite material and substrate [11,12]. In addition, unlike in the case of polymeric materials, special precautions regarding health hazards need not be taken when preparing and using cementitious materials. If all of the positive aspects associated with the use of a cement matrix are evaluated in combination with the advantages of using natural fibres in the production of fabric cementitious composites, then the use of these materials to solve problems of sustainability in the construction industry is revealed to be a promising area of research [13–16].

Several factors can influence the mechanical performance of fibre-reinforced composites. The fibre length, weight ratio, fibre orientation and interphase between fibres and the corresponding matrix material have significant effects on the tensile, flexural and fatigue behaviour [17–19]. Gassan [20], studying polymer composites reinforced with natural fibres, observed significant effects on crack propagation and fibre–matrix adhesion by considering factors such as textile architecture and fibre treatment. Similarly, in fabric-reinforced composites, the stiffness and the strength are controlled by the fibre and matrix properties, bond interphase and the anchorage of the fabrics in the matrix [21]. When considering cementitious composites reinforced with natu-

---

* Corresponding author at: Università della Calabria, Dipartimento Ingegneria Civile, Via P. Bucci, Cubo 39B, Rende (CS) 87036, Italy. Tel.: +39 3662 824 592; fax: +39 0984 496 924.

E-mail addresses: ocevallos@unach.edu.ec (O.A. Cevallos), renato.olivito@unical.it (R.S. Olivito).

http://dx.doi.org/10.1016/j.compositesb.2014.10.004

ral fabrics, both the mechanical response and the parameters affecting their behaviour are less well understood than those of other composite systems due to the lack of systematic and detailed information available.

This paper deals with the effects of different fabric parameters on the tensile behaviour of sustainable cementitious composites. The mechanical behaviour of cementitious composites produced with layers of reinforcing fabric strips was evaluated. Composite samples were produced using one, two or three layers of flax and sisal fabric strips. Because of their good mechanical properties compared to those of other natural fibres, flax and sisal fibres have been used to produce composite materials with great potential for strengthening structures [4,11,14,22]. The matrix used was a lime-based grouting (NLG) mix containing natural pozzolans and carbonated filler. Composites produced with an OPC (ordinary Portland cement) matrix undergo an accelerated ageing process due to fibre mineralisation and alkali attack related to variations in humidity [23,24]. Hence, using natural hydraulic lime (NHL) mortars guarantees the absence of any OPC binder and therefore the absence of harmful amounts of water-soluble salts. Indeed, the results of durability tests conducted by the authors on flax and sisal fibres aged in this NLG matrix [11] led to the conclusion that the lower alkalinity and the presence of carbonate filler and pure pozzolan with a high content of reactive silica makes this matrix potentially well suited for incorporation into vegetable fibre reinforcement composites. All composite samples were subjected to direct tensile tests. Various physical and mechanical properties of fabrics, such as the fabric geometry, mass per unit area, linear density, Young's modulus, tensile strength and strain to failure, were analysed. The effects of these fabric parameters, including the volume fraction of fibres, on the tensile behaviour and crack propagation of fabric-reinforced composites were studied.

Finally, to evaluate the effect of fibre type, mineral fibres (glass) were also considered, and glass fabric-reinforced composites were prepared and tested using the same test setup.

2. Experimental programme

2.1. Materials

The matrix employed was a natural hydraulic lime grouting (NLG) mix with added natural pozzolan and carbonate filler. The water content used for mixing this matrix was 240 kg/m^3, and was not modified by the addition of any other component. The mechanical characterisation of six prismatic specimens (160 mm × 40 mm × 40 mm) of the NLG matrix was conducted according to BS EN 1015-11:2007 [25]. The samples were cured for 28 days and then tested in bending and compression. Since its compression strength and flexural strength was 15 MPa (9.47% coefficient of variation (CoV)) and 5 MPa (12.79% CoV), respectively, this matrix can be classified as a masonry mortar type M15 according to BS EN 998/2 [26]. The particle size distribution of this cementitious material was 100% passing 0.09 mm and 90% passing 0.06 mm according to BS EN 1015-1 [27]. Its fluidity [28] (70–80 cm) and workability time [29] (195 ± 30 min) improve impregnation and simplify the arrangement of the reinforcing fibres. In addition, both its water absorption coefficient due to capillary (0.40 kg/m^2 min$^{1/2}$), measured according to BS EN 1015-18 [30], and low water-soluble salt content (<1.5%, of which chlorides are <0.03%) increase compatibility between the NLG matrix and masonry structures.

Bi-directional woven fabrics made from single yarns of natural fibres were used as raw material to produce the composite samples. Their architecture makes these fabrics lighter, compact and more suitable than unidirectional fabrics for specific applications requiring optimised structural weight. Since the natural fabrics used are woven fabrics, the resulting materials exhibit good stability in both directions (warp and weft) and a high yarn packing density in relation to the fabric thickness. The plain-fabric structure presented in Fig. 1a is one of the most common weave structures. Both the flax and sisal fabrics were symmetrically woven with a plain type structure using single yarns. In the sisal fabric (see Fig. 1b), each warp yarn passes alternately under and over each weft yarn, whereas it can be noted that the flax fabric structure (see Fig. 1c) was formed with two single yarns arranged in both directions. Table 1 summarises the physical and mechanical properties of the fabrics considered in this study. It is worth mentioning here that the flax fabrics were produced in Italy, whereas the sisal fabrics were manufactured in Colombia. In contrast to the flax fabrics, the sisal fabrics showed an irregular distribution of the yarn bundle size, mainly in the weft direction (see Fig. 1b), and the manual production processes used to weave these fabrics resulted in a wider variation in their physical and mechanical properties (see Table 1). In a previous study conducted by the authors [11], an extensive fibre characterisation of the flax and sisal fabrics used in this study was performed; various physical and mechanical properties of single yarns and fabric strips, such as the fibre diameter, density, linear density, yarn and fabric area, mass per unit area, Young's modulus, tenacity, tensile strength and strain to failure, were examined.

Over the past several decades, glass fibres have been widely used for producing composite materials based on polymers (FRPs) [31]. The high mechanical properties of these fibres are comparable to those of carbon fibres [32]; however, their low strain capacity generally results in glass fibre-reinforced cement (GFRC) compos-

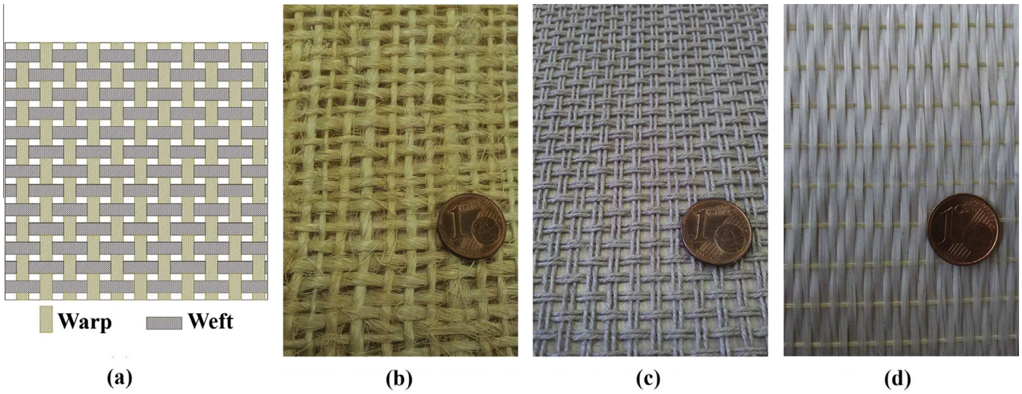

Fig. 1. Reinforcing fabrics: (a) plain fabric-structure; (b) bi-directional sisal fabric; (c) bi-directional flax fabric; and (d) unidirectional glass fabric.