Construction and Building Materials 100 (2015) 111–121

Contents lists available at ScienceDirect

Construction and Building Materials

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

Structural behaviour of masonry panels strengthened with an innovative hemp fibre composite grid

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HIGHLIGHTS

- An innovative strengthening system made of hemp-fibre composite grids was developed.
- The in-plane behaviour of hemp-fibre strengthened masonry panels was assessed.
- The shear strength enhancements were comparable with those obtained with FRP meshes.

ARTICLE INFO

Article history:
Received 28 July 2015
Received in revised form 21 September 2015
Accepted 25 September 2015
Available online 6 October 2015

Keywords:
Hemp fibres
Composite grid
Masonry panels
Strengthening
Diagonal compression test

ABSTRACT

Sustainability goals are essential driving principles for the development of innovative materials in the construction industry. Natural fibres represent an attractive alternative as reinforcing material due to both good mechanical properties and sustainability prerequisites. The present work investigates the shear behaviour of masonry panels strengthened with a mortar-based system reinforced with an innovative hemp fibre composite grid. The objective of the study is to assess the feasibility of using the proposed strengthening system for external retrofit of existing masonry walls and to compare its performances with typical retrofitting solutions.

1. Introduction

Over the last decade, the structural rehabilitation of existing buildings has increasingly attracted the attention of scientific community. A significant focus has been put on masonry structures due to the large portion of the existing building stock that they encompass in many European areas, such as Italy, as well as due to their important historical and cultural value. In addition, a large number of existing masonry structures is prone to damage as a consequence of a large number of possible actions, including earthquakes, environmental deterioration/aging, and other hazardous events.

In this context, several retrofit/strengthening techniques have been developed for these types of structures, often considering reversibility, compatibility and sustainability as beneficial prerequisites for the retrofit/strengthening process. Moreover, techniques based on the use of innovative technologies and materials compatible with physical and mechanical properties of the existing masonry structures are oftentimes required in order to improve their performance and provide economic benefits too. Among new strengthening strategies, the employment of strengthening techniques based on Fibre-Reinforced Polymers (FRPs) provides a series of advantages, including high strength-to-weight ratios, corrosion and fatigue resistance, negligible influence on global structural mass, easy handling and installation, and low architectural impact [1–5]. In terms of structural performance, the use of FRPs is able to significantly enhance the tensile strength and global ductility of masonry panels. However, some drawbacks are also related to these reinforcing materials, such as poor fire resistance,

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http://dx.doi.org/10.1016/j.conbuildmat.2015.09.051
0950-0618/

relatively high cost, environmental impacts and compatibility with masonry structures [6–9].

Over the last decades, sustainability objectives are becoming essential driving principles for the development of innovative materials and technological solutions in the construction industry [10,11]. Among proposed sustainable solutions, natural fibres represent an attractive alternative as reinforcing materials in structural applications due to both good mechanical properties and to the possibility to meet sustainability prerequisites [12–14]. From the side of mechanical properties, some natural fibres (such as hemp, flax jute, sisal etc.) are able to exhibit tensile strengths comparable with those exhibited by synthetic fibres [15,16]. Indeed, natural fibre reinforced composites are widely investigated in the research community, trying to exploit their potential to reduce or eliminate some of the problems connected with the poor recyclability of glass and carbon fibres in conventional composites [18–20]. In addition, the production process of natural fibres consumes globally less energy compared to typical fibres used in composite technology. However, the use of these fibres as reinforcement in composite materials remains a challenge mainly due technological issues, such as fibre orientation and compatibility with the matrix, and due to durability concerns [12,15–17].

In construction industry applications, the mostly investigated reinforcing natural fibres are the vegetable ones, especially bast fibres (jute, flax and hemp) [21,22]. In particular, both short fibre and textile reinforced mortars have been developed and investigated, mainly focusing on the reinforced material behaviour rather than on the scale of the final application [23–26]. A number of works have been also conducted on the development of natural fibre reinforced concrete [29,30].

As far as applications on structural members are concerned, only few studies have dealt with structural systems based on natural fibres. Focusing on masonry structures applications, Olivito and co-workers investigated a strengthening system made of inorganic matrix reinforced with a natural fibre fabric; the study started from the composite material scale, up to the scale of clay brick panels loaded under eccentric loads [27,28]. In particular, the external reinforcing system consisted in a natural hydraulic lime mortar combined with an untreated bi-directional flax fabric; they found that the low stiffness of the natural reinforcement prevented premature debonding between matrix and masonry units, allowing a good mechanical performance of the reinforced structure.

Nevertheless, while natural fibres are already largely used in many industrial applications, the employment of natural fibres in materials, components or systems for construction industry is still limited [31]. Variability of physical and mechanical properties along with durability issues (linked to environmental exposure of construction products) represent the main issues that are limiting the use of natural fibre based systems in construction applications [31,33]. Despite these drawbacks, a significant number of advantages can be envisioned by adopting natural fibres as an alternative to other fibres in many technologies and systems for construction industry: low density and weight, high specific strength, low CO_2 emission during the entire life cycle, non-harmful processing during the production phase, low cost [31].

The present work deals with the assessment of the in-plane structural behaviour of masonry panels strengthened with an innovative reinforcing system obtained by using two inorganic mortars combined with a hemp fibre composite grid. The present work integrates a long research activity on hemp fibre based strengthening systems for masonry structures; the first results of this activity were presented in the work by Asprone et al. [14]. In that previous work, the tensile properties of hemp fibres were investigated and the physical and mechanical compatibility of hemp fibre cords with a pozzolanic mortar was assessed. In details, severe degradation processes were experienced for hemp fibres in contact with the mortar, as a result of its alkalinity. Thus, latex and epoxy resin coating of the fibre cords were tested to inhibit the degradation, still guaranteeing a good mechanical bond between the fibre cords and the inorganic matrix. The epoxy resin finally exhibited the best mechanical performances on the hemp composite system.

The present work moves toward the scale of the structural application, focusing on the development of a strengthening system for masonry panels. A proper low viscosity epoxy resin is used to impregnate dry hemp cords of a bi-directional grid in order to maximise the load-bearing contribution and load transfer between hemp fibres and the inorganic matrix, guaranteeing a reduced stiffness and a good flexibility of the resulting fibre composite grid. This allows the grid to be bended and rolled, so to be easily delivered to the installation site, as in case of similar commercial reinforcing systems.

In the following sections we present the hemp fibre composite (HFC) grid that is used to reinforce both a natural hydraulic lime (NHL) and a pozzolanic mortar; then, these systems are employed to strengthen tuff and brick masonry panels. Diagonal compression tests are conducted on these panels and the results are elaborated to assess the mechanical performances of the strengthening system. The performances are compared with those exhibited by similar commercial systems where the composite grid was made of synthetic fibres.

2. Materials and experimental program

The experimental program consisted in diagonal compression tests carried out on 12 masonry panels. Among them, 6 panels were made of Neapolitan yellow tuff (NYT) bricks (390 mm × 250 mm × 115 mm of dimensions, supplied by a local quarry located near Naples, Italy) and 6 panels were made of solid clay bricks (250 mm × 120 mm × 55 mm of dimensions, supplied by Terreal San Marco S.r.L.). In all the panels, a pozzolanic and lime based mortar was used for the bed joints, with a thickness of about 10–12 mm. The resulting NYT panels were ten courses high and one block wide, having final dimensions of approximately 1200 mm × 1200 mm × 250 mm. The clay panels were eighteen courses high and one clay block wide, having final dimensions of approximately 1180 mm × 1180 mm × 250 mm.

The panels of each of the two sets (NYT panels and clay panels) were tested in three different configurations:

(i) Two unstrengthened panels used as control specimens (referred to as NYT-P and C-P series, for the NYT and clay panels, respectively).
(ii) Two panels strengthened on both sides by means of one layer of a HFC grid bonded with a pozzolanic mortar (referred to as NYT-HFC_PT and C-HFC_PT series, for the NYT and clay panels, respectively); on each side of the panel, the total thickness of the pozzolanic mortar layer which contains the HFC grid was equal to approximately 15 mm, and it is indicated as *t* in Fig. 1.
(iii) Two panels strengthened on both sides by means of one layer of HFC grid bonded with the NHL mortar (referred to as NYT-HFC_MW and C-HFC_MW series, for the NYT and clay panels, respectively); on each side of the panel, the total thickness of the NHL mortar layer which contains the HFC grid was equal to approximately 40 mm, and it is indicated as *t* in Fig. 1.

The strengthening systems were installed according the following procedure:

- Preparation of the masonry substrate by means of a cleaning cycle with high-pressure water.
- Pre-wetting until saturation of the substrate to prevent mortar drying out.
- Application of a first layer of mortar (thickness of about 5–8 mm and 20 mm for HFC_PT and HFC_MW series, respectively) onto both sides of the panel.
- Placement of one ply of HFC grid on each side of the panel (Fig. 2a).
- Application of a second layer of mortar to complete the installation procedure (thickness of about 5–8 mm and 20 mm for HFC_PT and HFC_MW series, respectively).

The two different total thicknesses of the matrix system ($t = 15$ mm and $t = 40$ mm, adopted for the pozzolanic and the NHL based mortar, respectively) are related to the properties of the two different mortars and to practical criteria employed for typical strengthening systems of masonry structures. The main