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Glass fabric reinforced cementitious matrix: Tensile properties and bond performance on masonry substrate

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ABSTRACT

Fibre-reinforced composite materials have gained an increasing success, mostly for strengthening, retrofitting, and repairing existing structures. However some problems may arise with the use of traditional FRP (Fiber Reinforced Polymer), particularly when the compatibility with the substrate and the reversibility of the intervention are required, as in case of cultural heritage buildings, or specific exposition conditions may compromise the long term effectiveness of the reinforcement, as in presence of high temperature and humidity. Starting from these considerations new composite materials are emerging as a more effective solution in certain fields of application and under specific service conditions; in this context, mortar-based composite systems, consisting of one or more layers of uni- or bi-directional fibre nets embedded in cement/lime-based matrix layers, can be used as reinforcement of both concrete and masonry structures. However, the research work dealing with these emerging materials and their performances when used as a strengthening system for existing structures is still limited. Both experimental and theoretical investigations are needed in order to deliver reliable design methodologies. In this work, a Round Robin Test aimed to the characterization of both bond with the existing substrate and tensile performance of glass fabric (in the form of grids) coupled with inorganic mortar matrices is presented. The investigation was conducted at fifteen laboratories involved in the RILEM Technical Committee 250-CSM (Composites for the Sustainable Strengthening of Masonry). With the aim of studying the bond behaviour between Fabric Reinforced Cementitious Matrix (FRCM) composites and masonry substrate, single and double lap shear tests were carried out on brick-masonry prisms. Results provide useful informations about the mechanical properties, the bond capacity and the failure mechanisms of different commercially available glass FRCM systems. Finally, critical aspects are underlined to address the progress of the research work.

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1. Introduction

The assessment of new retrofitting techniques is an important issue while enabling the design optimization when the safety of existing structures is addressed. Composite materials, among all Glass Fibre Reinforced Polymers (GFRP), have been used in structural applications since the first half of 20th century, however the high cost and the unfamiliarity with their mechanical behaviour (i.e. anisotropy) had slowed down their wide spread use in civil engineering.

In recent years, the use of GFRP materials (bars, plates, sheets) as external reinforcement for concrete structures has grown due to their superior properties compared to steel in terms of corrosion and fatigue resistance, lightweight characteristics, and high tensile strength to weight ratio. While an extensive research has been conducted for reinforced concrete structures strengthened by composite materials, limited work is still available when masonry constructions are concerned. The use of GFRPs to strengthen masonry structures first appeared in the USA in the 90s, where GFRPs strips epoxy bonded to the masonry substrate were utilized. However, the cost of GFRP (referring to both the composite material and the epoxy adhesive) and a mechanical improvement of the structure comparable to that obtained by conventional retrofitting methods has limited a widespread use of GFRPs as external reinforcement of masonry structures.

On the other hand, catastrophic earthquakes in many areas of the world have revealed the high vulnerability of masonry buildings, traditionally designed without special measures against the effects of horizontal loads. The damages caused by seismic actions on masonry buildings involved loss of human life, high costs of repairing and, in many cases, irreversible loss of cultural heritage.

Historic buildings represent a peculiar class of constructions not only because of their architectural value but also because of their social role. The need to be repaired or retrofitted is increased in the last years and this task is particularly challenging in earthquake-prone areas. Between 1995 and 2015, a series of experiments were carried out at several research centers across Europe and USA to assess effective strengthening techniques for historic masonry using GFRP materials (in the form of overlays, wraps or pre-preg laminates). The principal focus has been the structural upgrade of masonry elements against in-plane seismic action using continuous glass fibres sheet and GFRP plates, usually made by unidirectional fibres [1–9] Vaults and arches also received considerable attention in many papers dealing with GFRP reinforcements applied at the intrados or extrados of the curved elements [10–17]. Other papers have considered the reinforcement of stone or brick masonry columns by providing a confinement action using glass fibres [18–25]. In the last few years, many researchers have also investigated the bond between FRPs and masonry substrates by means of single and double face shear tests [26–40]. Thanks to the wide research efforts national and international guidelines have been assessed and now available for the design of unreinforced masonry structures strengthened by Externally Bonded EB-FRP systems [41,42].

A more innovative technique has been recently proposed in several studies [43–62]. In the early 2010s, the use of inorganic matrices/adhesives was considered with the aim to improve the long term behaviour of the strengthening intervention and meet the requirements of conservation of historic masonry structures, including reinforcement reversibility and reinforcement-to-substrate compatibility. This type of matrix, generally including cementitious and lime-based materials, has limited concerns regarding the cost, the health and the safety restrictions compared to organic adhesives. In this case, fibre rovings can be used in a dry or coated or resin-impregnated form.

According to the international [34] and Italian terminology the common acronym used to refer to these materials is FRCM (Fabric Reinforced Cementitious Matrix) which also account for system with cement-free matrices. Other acronyms as FRM (Fibre Reinforced Mortar) or TRM (Textile Reinforced Mortar) are often utilized.

The use of inorganic matrices needs to be validated with extensive research activities; their mechanical properties are significantly weaker compared to those of epoxy adhesives. In particular in the case of dry fibre grids the type of matrix and its thickness may greatly influences the mechanical performance of the composites.

In addition, the composite action of materials made by inorganic matrices and high performance fibers should be studied in depth. In the case of FRCM it is necessary to use alternative forms of fabric layouts: a 2D grid-like configuration constituted by fibre rovings arranged in (typically) two orthogonal directions provides the necessary mechanical interlock between the reinforcement (the grid or the textile) and the binding (the mortar that protrudes through the grid's openings) ensuring an adequate composite action. In addition, in the case of dry fibre rovings, the matrix-to-reinforcement bond characteristics are further enhanced by the eventual penetration of the mortar paste into the bundles.

In this paper, the analysis of the mechanical properties of Fibre Reinforced Cementitious Mortar specimens in terms of tensile and bond capacity are investigated. Due to the growing interest in the area of composite materials made by an inorganic matrix and the extremely high combination of variables associated with the use of FRCM, a wide research activity is needed. The aim of the present work is to contribute in deepening the knowledge on this topic enriching the limited existing literature. To this scope, fifteen laboratories have tested eight commercially available products that employ lime- or cement-based matrices. Research labs involved include: Cracow University of Technology (Cut), RWTH Aachen University (Aachen), Slovenian National Building and Civil Engineering Institute (ZAG), Polytechnic di Milano (Polimi), University of Bologna (Unibo), University of Firenze (Unifi), University of Minho (Uminho), University of Naples "Federico II" (Unina), University of Napoli 'Parthenope' (Unisannio), University of Padova (Unipd), University of Patras (Upatras), University of Perugia (Unipg), University of Roma Tre (Unirm3), University of Salento (Unisalento), University of Trieste (Units). The results herein reported furnish interesting scientific founds concerning the mechanical performance of FRCM and highlight critical aspects to be further investigated.

The results discussed in the present work represent part of the activities of RILEM Technical Committee 250-CSM "Composites for Sustainable Strengthening of Masonry". In particular, the study of the tensile and bond performance of FRCM systems involving 21 research centers and laboratories and 11 companies was performed. The main objectives of the planned research work were the evaluation and the comparison of the mechanical properties of different FRCM materials, made by glass, carbon [63,64], basalt [65], aramid, PBO [66,67], and steel [68] textiles.

Based on the previous considerations, the composite response under direct tension, the critical assessment of the related failure modes as well as the identification of the substrate-to-composite and reinforcement-to-matrix bond mechanisms were analysed and discussed. The scope is to furnish an effective contribute to the understanding of the resisting mechanisms of masonry elements retrofitted by inorganic matrix and fibres mesh.