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Characterization tests of GFRM coating as a strengthening technique for masonry buildings

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ABSTRACT

Fiber Reinforced Mortars (FRM) represents a promising technique for the in-plane and out-of-plane reinforcement of existing masonry buildings, coupling effectiveness with compatibility needs. The paper focuses on a technique consisting in the application on the masonry surface of a 30 mm thick mortar coating with Glass Fiber-Reinforced Polymers (GFRP) meshes embedded, presenting and discussing the results of several characterization tests (pull-out, lap-splice, bond and tensile tests) performed so to investigate on the tensile properties and bond performances of the strengthening system, useful for correct design procedures and suitable also for numerical modeling.

The main aspects that has to be taken into account in the design of characterization tests are evidenced and the influence of some fundamental parameters (as the clamping system, the anchorage length, the boundary conditions and the sample dimensions) is discussed. Moreover, proper characterization tests permitted the estimation of the anchorage length to make effective the reinforcement and the definition of the stress-strain curve of the reinforced material subjected to tensile force.

1. Introduction

The historical architectural substrate of many cities in the world is composed for the most of masonry constructions. Past and even recent seismic events extensively evidenced the high vulnerability of these buildings, due to the intrinsic low tensile strength of historic masonry and to design deficiencies against resistance to horizontal actions. The necessity to prevent in-plane and out-of-plane premature brittle failures of masonry elements with an effective reinforcement technique is frequently accompanied by the need to preserve the pre-existences, as often part of the cultural heritage.

The use of composite materials (based on fibers made of glass, carbon, aramidic, PBO...) in the structural retrofitting of masonry buildings started in the last decade of the XX century [1–3] and is gradually replacing traditional techniques employing steel elements and reinforced concrete, due to the competitive performances in terms of tensile resistance, lightweight, durability, fatigue behavior, no-corrosive and un-magnetic.

Depending on the element used (fabrics, strips, bars or meshes), the reinforcements are utilized in the mortar joint as reinforced repointing (Near Surface Mounted bars and strips – NSM), are glued directly to the masonry through either epoxy resin (Fiber Reinforced Polymers – FRP) or a thin mortar cement-based matrix (Fiber Reinforced Cementitious Matrix -FRCM) or are embedded in an inorganic mortar coating (Fiber Reinforced Mortars – FRM). Among the different available techniques [4–12], the use of Fiber Reinforced Mortars (FRM) or Textile Reinforced Mortars (TRM), is one of the most suitable for masonry elements. In fact, the use of inorganic matrix, instead of epoxy resins, to bond the reinforcement to the substrate ensures a better adhesion to an irregular surface such that of the masonry, provides fire resistance to the composite and protects it from UV rays and chemical agents. Moreover, the possible use of mortars made of natural binders, instead of cement, meets also the requirements of compatibility with historical masonry. Usually, the mortar layer thickness is of about 10 mm and the composites embedded in inorganic matrixes consist in unidirectional or bidirectional textiles or meshes (from 10×10 mm^2 up to 25×25 mm^2 grid dimension). These reinforcement methods have found application in the enhancement of masonry walls, columns, arches, vaults, bridges... However, despite the large number of experimental campaigns performed on the effectiveness of these techniques, limited investigations were conducted on the mechanical properties of these reinforcements in terms of tensile properties and bond performances on masonry substrate, useful to provide correct design procedures for an effective application and thus operation of the strengthening

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system. For this purpose, considering that the combination of variables associated with the use of FRMs is extremely high (e.g., matrix nature and thickness, textile material and percentage...), the RILEM Technical Committee 250-CSM "Composites for Sustainable Strengthening of Masonry" recently decided to deal with this specific topic, involving also, among the different activities, 15 laboratories for testing 8 GFRP (Glass Fiber-Reinforced Polymers) grid products coupled with different lime or cement matrices [13]. In fact, among the primary aims of the Committee, there is the identification and promotion of standardized experimental procedures for tensile and debonding tests on FRMs and the dissemination of proper application procedures for mortar-based composite materials on existing masonry structures.

The paper resumes the results of some characterization tests performed by the authors at the Laboratory of Building Materials and Structures of the University of Trieste, which was involved in the Round Robin Tests promoted by the Technical Committee 250-CSM. In particular, the analysed reinforcement technique consisted in GFRP preformed meshes (usually $66 \times 66\,mm^2$ grid dimension) embedded in a 30 mm thick mortar layer. The durability behavior of the GFRP grids exposed to various environmental conditions was investigated by Corradi et al. [14]. The effectiveness of the technique in the seismic enhancement of masonry walls (in-plane and out-of-plane) and vaults was investigated [15–18]; in these studies the importance of a good bond between the reinforcement and the masonry substrate and between the mesh and the mortar matrix emerged.

The presence of a mesh grid dimension and a mortar thickness outside of the usual standards for FRMs necessitated the execution of some preliminary tests (pull-out and lap-splice tests) on elemental samples, to check the interaction between the GFRP mesh and the mortar matrix. The results, which are resumed in the paper, had the intent to detect the main aspects which has to be taken into account in the proper design of the characterization tests for the considered reinforcement technique. Then, the shear and tensile characterization tests performed on GFRP reinforced mortar samples are described and discussed in detail. In particular, observations on the different failure mechanisms occurred in bond test at the varying of the bond length and of the mesh grid pitch and in tensile tests at the varying of the sample dimensions, gripping system and mesh grid pitch are made. Characterization tests permitted the assessment of the anchorage length to make effective the reinforcement and the definition of the stress-strain curve of the reinforced material (FRM), suitable also for numerical modeling.

2. Technique description and material characteristics

The GFRM technique (Fig. 1) consists in the application, on the masonry wall or vault surface, of a thin layer of scratch, the execution of some holes (25 mm diameter), the application of the GFRP mesh, the insertion of L-shaped GFRP connectors into the holes, injected with thixotropic cementitious mortar. To improve the anchorage of the connector in the mortar layer, an additional GFRP mesh device is used. Finally, a mortar coating, about 30 mm thick is applied.

The wires of the GFRP meshes are composed of Alkali-Resistant glass fibers embedded in a thermosetting resin made of epoxy vinylester with benzoyl peroxide as catalyst. The mesh is formed by twisting the fibers of the wires in one direction across the wires in the perpendicular direction, which fibers, differently, remain parallels (Fig. 2). The GFRP meshes used in practice for such a reinforcement technique have grid dimensions of $33 \times 33\,mm^2$, $66 \times 66\,mm^2$ and $99 \times 99\,mm^2$; the dry fiber cross section in a wire is $3.8\,mm^2$.

Preformed GFRP meshes are produced in rolls, with twisted fibers wires in the warp direction and parallel fibers wires in the weft one. Thus, for simplicity and speed of installation, the twisted fibers wires are commonly oriented in the vertical direction of a masonry wall and in the transversal direction of a masonry vault.

The main geometrical and mechanical characteristics of the GFRP wires are summarized in Table 1.

The global equivalent cross section of the wires was detected, according to the procedure presented in CNR DT 203/2006, Appendix B [19]. The tests consisted in immersing some portions of the wires (minimum total length of 200 mm) in a graduated cylinder filled with water and measuring the volume increase of the liquid.

Tensile tests were performed according to CNR DT 203/2006, Appendix B [19]. The test samples were constituted by single wires having a length of about 500 mm extracted from the mesh by cutting in half the transversal wires. The clamping heads were created by inserting both the ends of the wire in an aluminum cylinder (diameter 19 mm, thickness 1.5 mm, length 100 mm) injected with a high-performances bi-component epoxy anchoring. A universal testing machine "Galileo" was used (Fig. 3.); the load was measured using a pressure transducer (capacity 20 kN), connected with a digital acquisition system interfaced with a laptop. To survey the axial elongation during test, a linear potentiometer transducer was applied (10 mm, error lin. ± 0.10%, base length of 63 mm).

The twisted fibers wires showed a tensile resistance lower than that of parallel fibers wires. This is probably due to the different tension occurring in each fiber during the tensile test, because of the twisting, so that not all fibers reach the ultimate resistance at the same time. During the tensile tests of twisted fibers wires, a gradual untwisting was noted at the increasing of the load.

In the considered reinforcement technique, different types of mortar may be utilized for the coating made with calcareous or siliceous sand and using natural binders, cement and pozzolanic additives [20]. As an example, a lime and cement mortar (300 kg of hydraulic lime and 100 kg of Portland cement per m^3 of mortar) with siliceous sand was here considered for characterization tests. Experimental tests on prismatic ($40 \times 40\,mm^2$ cross section, 160 mm length) and cylindrical (100 mm diameter, 200 mm height) samples evidenced for such a mortar an average compressive strength $f_{c,c} = 6.3$ MPa (COV 11%) [21], a flexural tensile strength $f_{f,c} = 1.6$ MPa (COV 3%) [21], a tensile strength $f_{t,c} = 1.1$ MPa (COV 8%) [22] and an average Young modulus $E_c = 14430$ MPa (COV 14%) [23].

3. Pull-out and lap-splice tests

Some preliminary tests were carried out on very simple, small size mortar specimens with GFRP mesh embedded, so to detect the main aspects which may influence the interaction between the composite and the inorganic matrix and determine the most suitable test setup for the characterization of this reinforcement technique. For such a purpose, pull-out and lap-splice tests were performed. It is observed that test focuses on twisted fibers wires oriented in the load direction, accounting for the typical mesh positioning in masonry walls subjected to out-of-plane vertical bending and masonry vaults subjected to horizontal transversal loads (see Section 2). However, some comparisons with the parallel fibers wires bonding performances are made.

3.1. Pull-out tests

The pull-out test samples consist in $30 \times 180 \times 180\,mm^3$ mortar plates with $66 \times 66\,mm^2$ GFRP mesh embedded centered in the mortar thickness. Two transversal, parallel fibers, wires and three longitudinal, twisted fibers, wires were considered; the