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Moisture-induced degradation of interfacial bond in FRP-strengthened masonry

Hamid Maljaee*, Bahman Ghiassi [1], Paulo B. Lourenço [2], Daniel V. Oliveira [3]

ISISE, University of Minho, Department of Civil Engineering, Azurém, 4800-058 Guimarães, Portugal

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ABSTRACT

Externally bonded strengthening of masonry structures using Fiber Reinforced Polymers (FRPs) has been accepted as a promising technique. Although the effectiveness of FRPs in improving the performance of masonry components has been extensively investigated, their long-term performance and durability remain poorly addressed.

This paper, tackling one of the aspects related to durability of these systems, presents an experimental investigation on the effect of long-term (one year) water immersion on the performance of GFRP-strengthened bricks. The tests include materials' mechanical tests, as well as pull-off and single-lap shear bond tests, to investigate the changes in material properties and bond behavior with immersion time, respectively. The effect of mechanical surface treatment on the durability of the strengthened system as well as the reversibility of the degradation upon partial drying are also investigated. The experimental results are presented and critically discussed.

1. Introduction

Modern composite materials such as Fiber Reinforced Polymers (FRP) have been increasingly used for Externally Bonded Reinforcement (EBR) of masonry structures due to their good mechanical properties, lightweight, and ease of application. FRPs are expected to have longer lifetime and lower maintenance requirements in comparison with conventional materials used for strengthening of civil structures [1]. The available information in the literature shows that EBR strengthening of masonry structures with FRP composites leads to a significant structural improvement, which is strongly correlated with the performance of the bond between the repair material and the substrate [2].

As the bond behavior is a key mechanism in the effectiveness of EBR systems [2–4], a clear understanding of its durability and long-term performance is critical for structural design and service life predictions [5–7]. The durability of bond in FRP-strengthened concrete elements has been extensively studied, see e.g. Refs. [8–10], while only few experimental studies can be found on masonry elements strengthened with FRP composites, see e.g. Refs. [5,11–13]. The bond behavior and its durability are affected by different factors including environmental conditions, composite material used, substrate properties, interfacial adhesion and the applied surface preparation. Environmental degradation agents that are likely to affect the performance of structural materials are moisture, alkalinity, temperature, creep, ultraviolet light and fire [1]. Moisture has been recognized as a critical agent that can reduce the bond shear strength, peak slip, integrity at the bond level and fracture energy in FRP-bonded elements [5,14,15]. The presence of water may cause unwelcomed changes at the level of matrix/substrate interface, as well as in fiber and polymer structures. Indeed, diffusion of water into organic polymers can result in chemical, mechanical and thermophysical changes. Water may create a weak boundary layer at the interface between composite material and the substrate. It is known that the interfacial fracture energy of the bonded region decreases due to moisture exposure [15,16]. In terms of chemical effects, water molecules can bind to the resin through hydrogen bonding and disrupt van der Waals forces inside the pore network, known as hydrolysis mechanism [17].

Despite the extensive information on the effect of water on the mechanical properties of epoxy resins and bonded joints, its effects on the bond in FRP-masonry systems have been rarely

* Corresponding author. Tel.: +351 253 510 499; fax: +351 253 510 217.
E-mail addresses: h.maljaee.civil@gmail.com (H. Maljaee), bahmanghiassi@civil.uminho.pt (B. Ghiassi), pbl@civil.uminho.pt (P.B. Lourenço), danvco@civil.uminho.pt (D.V. Oliveira).
[1] Tel.: +351 253 510 499; fax: +351 253 510 217.
[2] Tel.: +351 253 510 209; fax: +351 253 510 217.
[3] Tel.: +351 253 510 247; fax: +351 253 510 217.

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studied [5,11]. Sciolti et al. [11] investigated the effect of approximately six months water immersion on the bond performance in CFRP-strengthened calcareous stones and observed a 26% reduction in the bond strength at the end of the tests. Ghiassi et al. [5] investigated the effect of six months water immersion on the bond behavior of GFRP-strengthened handmade clay bricks (with a relatively low compressive strength of 9.1 MPa and no surface treatments) and observed a significant reduction of bond strength and fracture energy. However, in both cases, it was not clear if the degradation reached a plateau at the end of exposure or could further increase with exposure. The effect of surface treatment on durability of these systems as well as the reversibility of the observed degradation upon drying are also unknown. In addition, as masonry structures are made of rather a wide range of materials and unit shapes, investigating the durability of FRP-strengthened masonry systems considering different substrates is necessary.

This paper presents the effect of long-term (one-year) water immersion on the bond behavior and material properties in GFRP-strengthened (industrially produced) extruded bricks. The effect of mechanical surface treatment (grinding of the bricks' surfaces) on the durability of bond as well as reversibility of the observed degradation upon partial drying are also investigated.

2. Experimental program

The experimental program consisted of one-year water immersion of GFRP-strengthened bricks and material constituents for investigating the water-induced mechanical degradation in the bond behavior and material properties. The specimens, after preparation and curing in the laboratory conditions, were immersed in water tanks specifically prepared for these tests. They were then periodically removed from the water (after different immersion periods) to perform the post-aging tests.

The post-ageing tests included weighing, visual inspection and mechanical characterization tests (materials tests and bond tests). The materials' mechanical tests included compressive tests on brick specimens and tensile tests on epoxy, primer and GFRP specimens. The bond characterization tests included pull-off and single-lap shear debonding tests.

The reversibility of the observed degradation was also investigated by testing (a) one set of specimens immediately after removal from water and (b) another set of specimens after one month storage in the laboratory conditions (20 °C and 60% R.H). The associated results are presented throughout the paper as “Wet” and “Partially dried” for the first and second group of specimens, respectively.

2.1. Materials and specimens

Materials consisted of (industrially produced) extruded solid clay bricks with dimensions of $200 \times 100 \times 50$ mm^3 as the substrate and GFRP sheets as the strengthening material. GFRP sheets were prepared following the wet lay-up procedure by impregnating a commercially available unidirectional E-glass fiber with a compatible two-part epoxy resin as the matrix. The epoxy resin was also used for adhesion of the GFRP sheets to the brick surface. A two-part epoxy primer was used for preparation of the bricks' surfaces before application of GFRP sheets.

The specimens prepared for material characterization tests included 40 mm cubic brick specimens, see Fig. 1(a), dog-bone shaped epoxy and primer specimens, see Fig. 1(b), and GFRP coupons, see Fig. 1(c). The epoxy resin, primer and GFRP coupons were prepared according to the manufacturer's technical datasheets and ISO 527-1 [18] specifications. The specimens were cured for two months in the laboratory conditions before performing the tests as also followed in Refs. [12,13].

Two groups of specimens were prepared, following the wet lay-up procedure, for bond characterization tests. The first group was prepared without application of any mechanical surface treatment on the bricks' surfaces (denoted as ORG-specimens). These specimens were prepared for pull-off and debonding tests. The second group, consisting of only single-lap shear test specimens, was prepared using bricks with grinded surfaces (denoted as GR-specimens). In both sets of specimens, the bricks were initially cleaned and dried in an oven (for 24 h at 100 °C) followed by

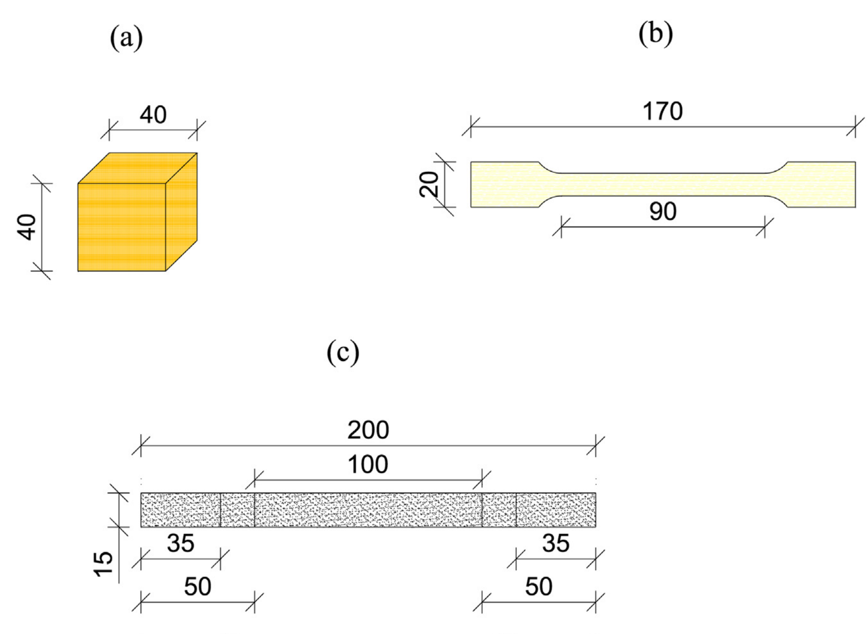

Fig. 1. Geometry of specimens prepared for material characterization: (a) brick cubes; (b) epoxy resin and primer; (c) GFRP coupon (dimensions are in mm).