Investigating the durability of FRP-masonry elements immersed in water

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ABSTRACT

Nowadays, there is an increasing interest in using fiber reinforced polymers (FRP) for strengthening masonry elements. It has been observed that these materials, when used for externally bonded reinforcement (EBR), improve the performance of masonry components. However, issues such as durability and long-term performance of strengthened elements are still open. The bond between composite material and masonry substrate is a critical mechanism in EBR strengthening techniques, and therefore its durability and long-term performance should be deeply investigated and characterized. In the present study, the influence of water immersion on the bond performance is investigated by performing single-lap shear bond tests on two sets of GFRP-strengthened specimens immersed in water for six months. Different surface preparation techniques are used for each set of specimens to study their effect on the bond degradation. The specimens are prepared following the wet lay-up procedure. The observations and the obtained results are presented and discussed.

Keywords: FRP; Bond; Durability; Moisture; Masonry

1 INTRODUCTION

Strengthening Civil Engineering structures with composite materials using Externally Bonded system (EBR) is becoming a promising method among engineers. The long-term performance of bond between masonry substrate and composite materials is considered as the main factor affecting the reliability and efficiency of these systems. A clear understanding of aspects such as durability and long-term performance is thus critical for structural design and service life prediction [1]. Long-term behavior of bond in FRP-strengthened concrete elements has been extensively studied, see e.g. [2, 3, 4], while only few experimental studies can be found on masonry elements strengthened with FRP

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composites, see e.g. [5, 6]. The environmental degradation agents that likely affect the performance of structural materials are moisture, alkalinity, temperature variations, creep, ultraviolet light and high temperatures [7]. Moisture has been recognized as a crucial agent that can reduce the bond shear strength, peak slip, integrity at the bond level and fracture energy in FRP-bonded elements [8, 9, 10].

As a deteriorating factor, the presence of water may cause initiation of unwelcomed changes at the level of matrix/substrate interface, as well as fiber and polymer structure. Indeed, diffusion of water into the organic polymers can result in chemical, mechanical and thermophysical changes [11]. Water may create a weak boundary layer at the interface level between composite material and the substrate. The interfacial fracture energy of the bonded region decreases due to moisture exposure [10, 12]. In terms of chemical effects, water molecules can bind to the resin through hydrogen bonding and disrupt van der Waals forces inside the network, inducing enhancement of segmental movements [13], which is known as hydrolysis mechanism.

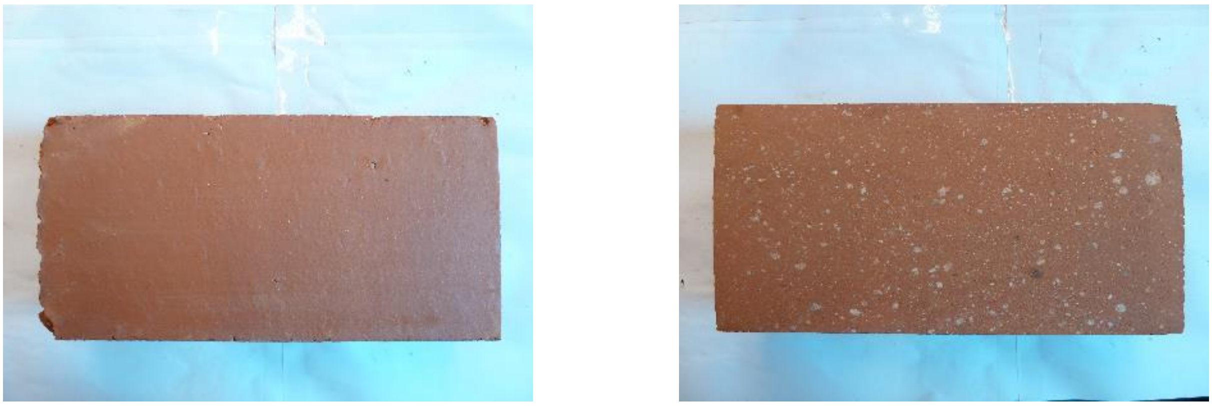
Ghiassi et al [14] reported a reduction of 15% and 23% in bond strength of GFRP-brick specimens subjected to four and eight weeks of immersion in water, respectively. In another study, it was observed that the bond strength of FRP-brick samples decreased by 35% during 20 weeks of water immersion [5]. Sciolti et al [6] found average drop of 23% and 26% in the bond strength between CFRP and natural calcareous stones after 8 and 25 weeks of water immersion. The available data are still few and performing further experimental tests with focus on different FRP composites, bricks and surface treatment techniques is required for obtaining a deep understanding of the degradation mechanism and development of predictive models.

In this paper, the effect of water immersion on the bond between GFRP and masonry bricks is assessed by performing single-lap shear tests. The specimens are immersed in water after initial curing in the laboratory conditions and are tested after different immersion periods. Two sets of specimens are prepared and tested to investigate the effect of substrate surface treatment on the bond degradation. The first set consists of specimens prepared without any surface treatment, while the bricks surfaces are grinded in the second set of specimens. The experimental results and observations are presented and discussed in terms of changes in the debonding load and failure mode.

2 EXPERIMENTAL STUDY

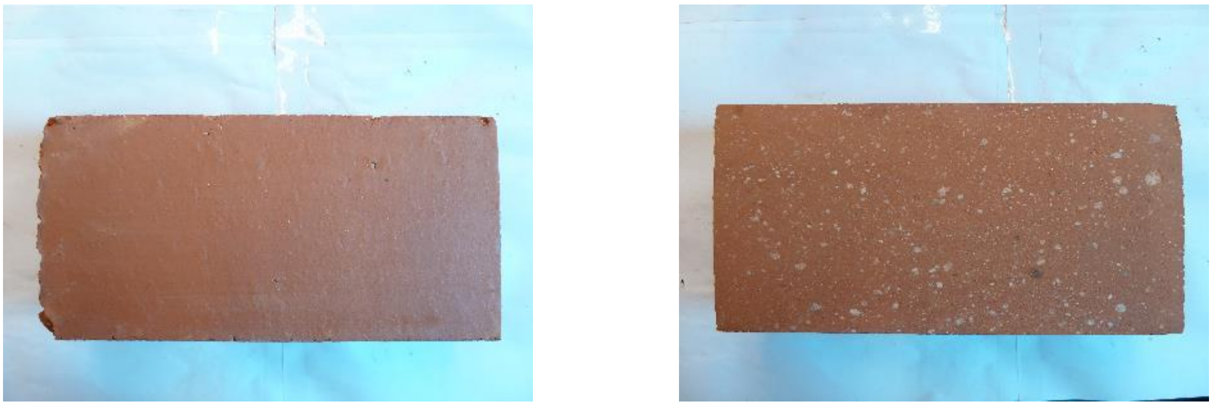
2.1. Test program

The study aimed to investigate the bond degradation mechanism in GFRP-brick specimens subjected to water immersion. The effect of preparation of brick surface was also investigated by choosing two groups of specimens including original brick surface (denoted as ORG-specimens) and grinded brick surface (denoted as GR-specimens), see



(a) **(b)**

Figure 1. All the specimens were immersed in water tanks for eight months under controlled temperature conditions (20˚C). The specimens were removed regularly (every month for the ORG-specimens and every two months for GR-specimens) from the water tanks to characterize the bond degradation. Single-lap shear tests were performed in order to investigate the changes in the bond behavior between GFRP and brick substrate.



(a) **(b)**

Figure 1. Bricks with: (a) no surface treatment; (b) grinded surface

2.2. Test specimens

The specimens were made of clay bricks with dimensions of 200×100×50 mm^3 strengthened with unidirectional glass fibers following the wet lay-up procedure. The bricks surfaces in the GR-specimens were grinded with an electronic saw. The bricks were then completely cleaned and dried in the oven. A layer of primer was initially applied on the bricks surfaces before application of the epoxy resin. This was followed by application a layer of epoxy resin on the bricks surface. GFRP sheets were then impregnated in epoxy resin and applied on the bricks surfaces, see Figure 2. The specimens were cured in laboratory conditions for 2 months before immersing in water.

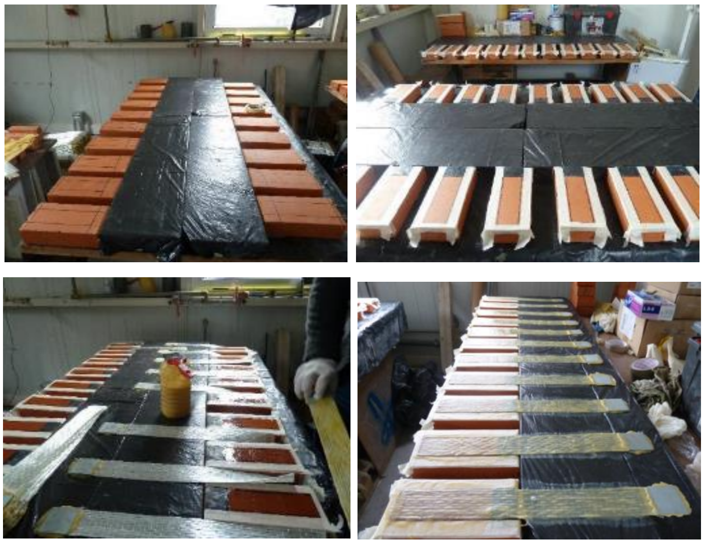


Figure 2. Specimens preparation

2.3. Material properties

The mechanical properties of materials were characterized by performing suitable experimental tests according to relevant test standards. A short discussion of the test methods and obtained results are presented in this section.

The compressive strength of masonry bricks were obtained according to standards UNI EN 1015-11 (2007) [15] and ASTM C67-12 [16]. The tests were performed on 40 mm brick cubes in the flatwise direction under force controlled conditions with a constant rate 150 N/min.

The mechanical characteristics of epoxy resin and primer were determined by performing tensile tests on dog-bone shape specimens cured in laboratory conditions for two months, following ASTM D638 (2010) [17]. The tests were performed under displacement controlled conditions with a constant rate of 2 mm/min.

The tensile strength and elastic modulus of GFRP were also obtained by conducting tensile tests on GFRP coupons, prepared following the wet lay-up procedure, based on ISO TC71/SC 6 N (2003) [18] and ASTM D3039 (2008) [19]. The tests were performed under displacement controlled conditions with a constant rate of 2 mm/min.

The typical failure modes of the specimens after performing the mechanical tests are presented in Figure 3 and Figure 4. The mechanical properties of materials together with coefficient of variations of the results are presented in Table 1.

Figure 3. Typical failure mode of brick, epoxy resin and primer

Figure 4. Typical failure mode of GFRP coupons

Table 1. Characterization of materials

Material	Tensile strength (MPa)	Elastic modulus (GPa)	Strain at peak load (%)	Compressive strength (MPa)
Brick	——	——	——	16.7 COV: 10%
Epoxy resin	40.9 COV: 11.6%	2.3 COV: 2.6%	2.1 COV: 16%	
Primer	38.6 COV: 19.8%	2.5 COV: 3.8%	1.6 COV: 24.2%	
GFRP	1087.4 COV: 17.6%	58.18 COV: 3.9%	1.9 COV: 11.6%	

2.4. Single-lap shear tests

Single-lap shear bond tests were conducted on the specimens after different periods of water immersion. The tests were performed using a universal testing machine with maximum capacity of 50 kN. The specimens were loaded monotonically with a constant rate of 5µm/sec under displacement control conditions. The specimens were connected to a steel frame and firmly clamped to it to avoid any rigid body movements during the tests, see Figure 5. The specimens were also typically instrumented with LVDT to monitor the relative slip between GFRP sheet and brick substrate.

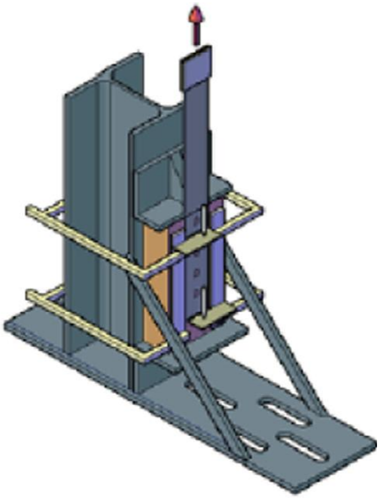
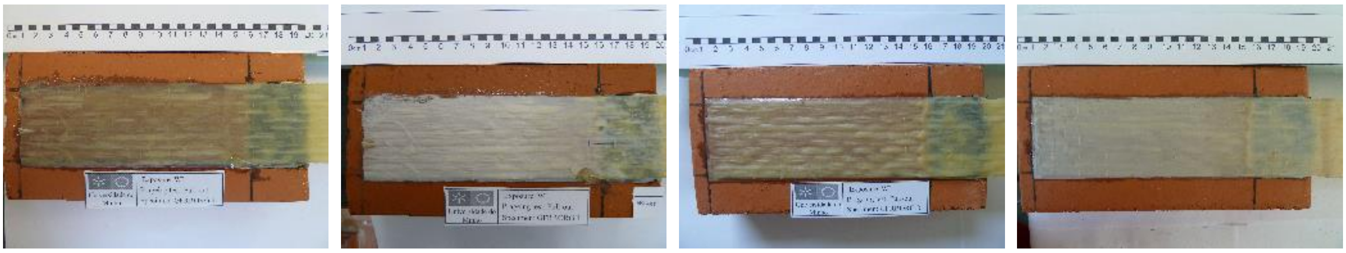


Figure 5. Schematic of single-lap shear test setup

3 RESULTS AND DISCUSSION

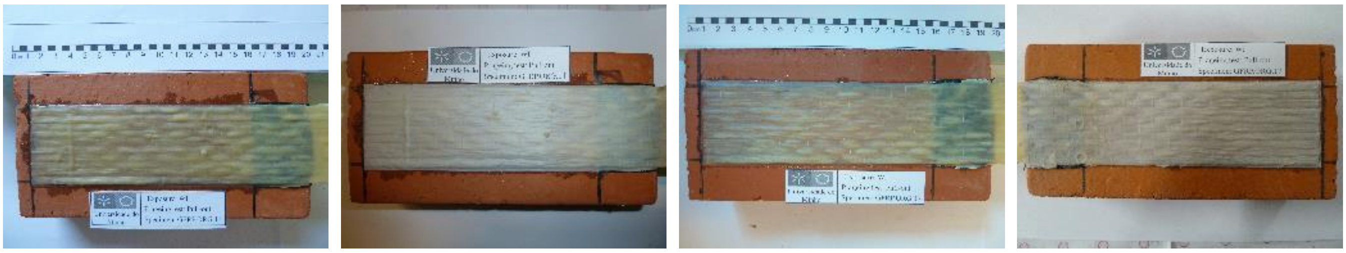
3.1. Visual inspection

The specimens were visually inspected upon removal from the water bath to investigate any changes or delaminations in the specimens. A comparison between the photos taken form the specimens before and after immersion, Failure modesee **Figure 6** for some representative specimens, shows that the color of GFRP sheet is changed due to water immersion. This may be the result of chemical reactions between water molecules and composite material which should be further investigated. However, no interfacial delaminations were observed in the specimens after removing from water.



Before immersion After immersion Before immersion After immersion

(a) (b)



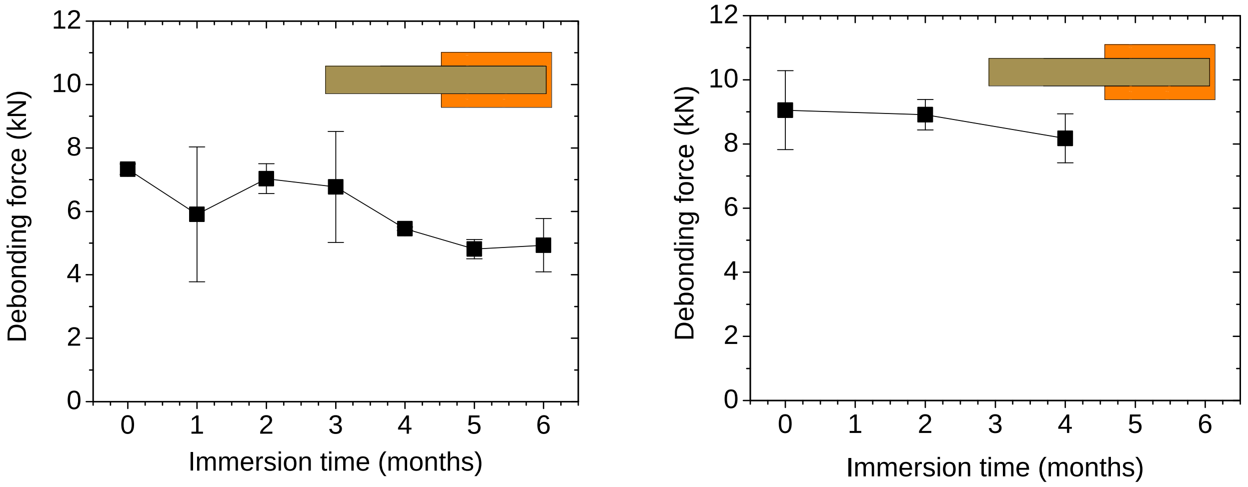
Before immersion After immersion Before immersion After immersion

(c) (d)

Figure 6. Changes in appearance after: (a) one (b) two (c) four and (d) five months of water immersion

3.2. Debonding force

The changes in the debonding force of both types of specimens (ORG- and GR- specimens) with water immersion are illustrated in Figure 7. A relatively significant reduction can be observed during six months of exposure for both specimen groups. It can be observed that the reference GR-specimens had higher debonding force (average 9 kN) than ORG- specimens (average 7 kN comparing). Moreover, they suffered less reduction in the debonding force than ORG-specimens during the mentioned period. It can be seen that the ORG-specimens experienced only a slight reduction of 7.6% during the first three months of exposure, while the decreasing rate accelerated (reaching 32.7% reduction) after six months of water immersion. As a comparison, GR-specimens showed 9.7% reduction of debonding force after four months of water immersion being less than the 25.5% reduction observed in ORG- specimens at the same immersion period, see Figure 8. The average values of the debonding force together with their coefficient of variation are presented in Table 2 for both specimen sets and all immersion periods.



(a) (b)

Figure 7. Changes of debonding force with water immersion: (a) ORG- specimens and (b) GR- specimens

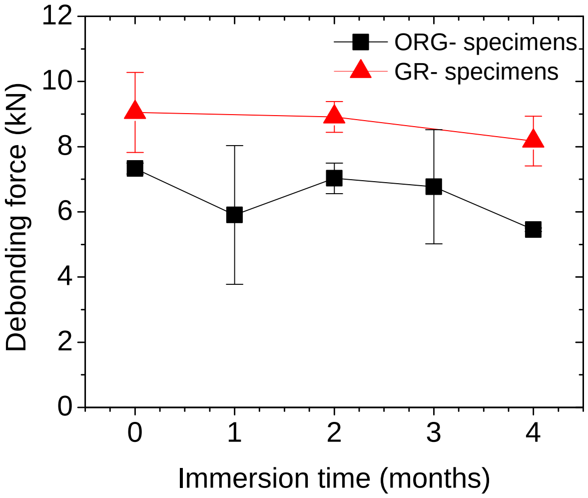


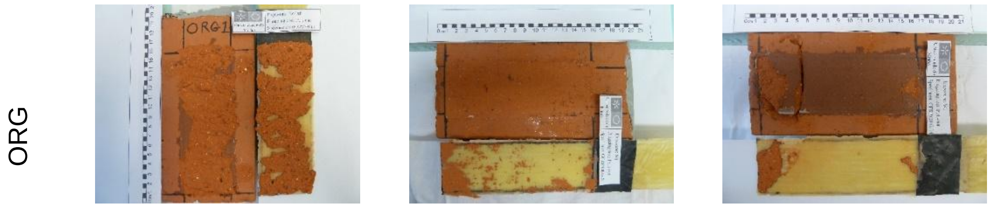
Figure 8. Comparison of changes in debonding force for the first four months of water immersion

Table 2. Average values of debonding force in different months of exposure

		No immersion	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6
ORG	Average (kN)	7.32	5.90	7.03	6.77	5.45	4.81	4.93
	COV (%)	2.3	36.0	6.7	25.8	1.0	6.3	17.0
GR	Average (kN)	9.05	___	8.91	___	8.17	___	___
	COV (%)	13.6	___	5.3	___	9.3	___	___

3.3. Failure mode

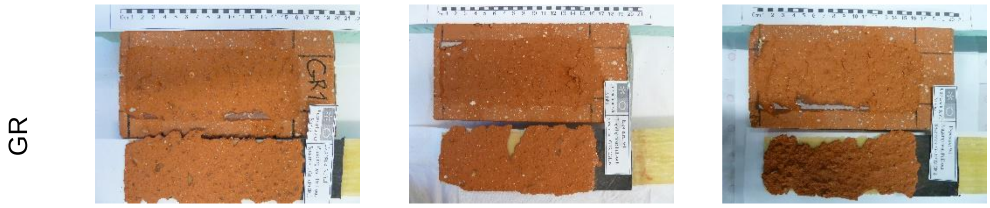
The influence of water immersion on the failure mode of the specimens can be clearly observed in Figure 9. The change of failure mode from cohesive to adhesive was the main effect of water on the ORG-specimens. Nevertheless, the mode of failure in GR-specimens was not changed and remained cohesive in the substrate in all the immersion periods. However, the thickness of the remained detached brick on the GFRP sheet was observed to decrease with time.



No immersion

2 months immersion

4 months immersion



No immersion 2 months immersion 4 months immersion

Figure 9. Changes of failure mode with water immersion

4 CONCLUSION

The results obtained from an ongoing experimental study aimed at investigating the effect of water immersion on the bond mechanism in GFRP-strengthened brick specimens were presented. The effect of substrate surface preparation on the bond degradation was assessed by preparing two sets of specimens: (a) bricks with original surface (ORG-specimens) and (b) bricks with grinded surface (GR-specimens) as the substrate. All the specimens were subjected to water immersion for six months under controlled conditions of 20˚C. The results obtained from the single-lap shear tests on the specimens after water immersion showed that the reduction of debonding force in GR specimens was less than ORG-specimens. The ORG-specimens showed a drop of 25.5% during four months of immersion, while GR-specimens presented only 9.7% reduction. A change of failure mode from cohesive to adhesive was observed in ORG-specimens. Meanwhile, the debonding occurred in the substrate in all GR-specimens during the exposure. A change of GFRP color was also observed in all the specimens with water immersion.

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