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Bonding and anchoring of a CFRP reinforced render for the external strengthening of old masonry buildings

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HIGHLIGHTS

- An innovative strengthening solution for loadbearing masonry wall buildings.
- The strengthening efficiently is dependent on bonding and anchorage behaviour.
- The experimental campaign allowed the validation of an end anchorage detail.
- The same campaign also served to prove that continuous bonding is ensured.

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ABSTRACT

This paper presents part of the results of an experimental study undertaken to develop a structural strengthening technique for old masonry buildings. The technique consisted of external reinforcement with a CFRP (Carbon Fibre Reinforced Polymer) reinforced render.

CFRP reinforced render is an innovative seismic structural strengthening material for the structural masonry walls of old buildings. It consists of a non-cementitious mortar reinforced with a carbon fibre mesh and is applied to one or both wall faces (preferably by shotcreting). The reinforced render material was developed to improve the mechanical capabilities of masonry walls subjected to "in-plane" and "out-of-plane" seismic loads. Similarly to other widely known composite materials (e.g., reinforced concrete) the composite behaviour of the reinforced masonry relies on both the anchoring as well as on the adhesion of the reinforcing material to the masonry substrate. These aspects are the main objectives of the presented experimental work.

The tests carried out in this study included the mechanical characterisation of all the materials involved, specifically of the mechanical behaviour of the reinforced composite render material, and finally focused on the bonding characteristics between CFRP reinforced render strips and masonry substrates, as well as the anchoring solution for the ends of the strips. The present experimental work is part of a research project to develop an innovative seismic strengthening technique for load-bearing masonry wall buildings.

1. Introduction

Most of the historic centres in Europe and elsewhere are predominantly composed of loadbearing masonry buildings. As repeatedly shown in previous earthquake events these buildings are known to present some weaknesses when subjected to earthquakes. These weaknesses can be further aggravated by natural deterioration that has occurred over time.

The present article reports part of the development stages of a new strengthening technique for load bearing masonry wall structures. It consists of replacing the external render (or plaster) with a non-cementitious mortar reinforced with a carbon fibre mesh applied to one or both sides of the wall. This external layer should provide tensile strength and flexibility, thereby benefitting both in-plane and out-of-plane collapse mechanisms [1–3]. Some of the critical aspects of this strengthening technique lie in the bonding behaviour (to the existing masonry wall) and in the anchoring of the ends and of any singularities [4–6]. Given this assumption, the present paper reports the experimental work carried out with the purpose of assessing the bonding behaviour and developing efficient anchoring devices for CFRP reinforced render strips.

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2. State-of-the-art

The oldest architectural heritage is at risk due to lack of appreciation and proper maintenance. Some of that heritage may already be irretrievably lost and some of what remains could be endangered. Their intrinsic nature and history (material and constitution) mean that these structures of architectural heritage present particular challenges for diagnosis and restoration that limit the application of current regulations and standards applicable to buildings. The recommendations [7–10] set out some of the principles of the restoration of old heritage buildings, the majority of which were followed when devising the strengthening technique under study.

The conception of this strengthening technique is largely based on another, described in [11–12]. Initially called "Sheet or composite fabric application to structural elements for bending or tensile reinforcement" or "ComRehab System", this technique involves applying a reinforcing mesh (Fig. 1) composed of strips of high performance polymer fibres (generally glass) – GFRP (Glass Fibre Reinforced Polymer) or CFRP – designed to function as external reinforcement on masonry walls. This reinforcement technique also recognises the importance of having a proper anchorage at the ends of the composite reinforcement due to the concentration of forces that tends to occur at these points. As such, the technique envisages that the ends of the reinforcing mesh are anchored in angle ties, both at their connection to the base of foundation and at the floors, to ensure the continuity of the reinforcement where there is an interior application on front masonry walls.

The ComRehab project aimed to design and study a system for strengthening old building structures, using low-cost composite materials like glass fibre composites (GFRP) [11,12]. The reinforcement system developed under the project was intended to give reinforced buildings good levels of performance for high and low intensity earthquakes, in particular, operationality for moderate severity seismic events with a short return period and for saving lives and/or preventing collapse in the event of a high intensity earthquake, i.e., with a long return period.

The effectiveness of such a strengthening technique – creation of an external layer that withstands tensile stresses – is highly dependent on the adhesion of the strengthening layer to the masonry substrate. Another critical aspect of these strengthening solutions concerns the sound anchoring of the strengthening layers (or strips). Awareness of this had already led to an extensive bond testing programme [11,12] that focused on characterising the adhesion of glass fibre reinforced polymer strips (initial version of the strengthening solution) to the masonry substrate, with or without resorting to mechanical anchorages (that also produced the side effect of confining the masonry wall).

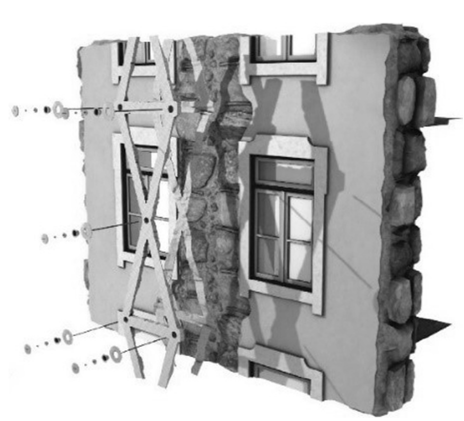


Fig. 1. Layout of ComRehab System [11].

In all, twenty-nine experimental specimens were tested using the same setup, composed of two separate blocks (Fig. 2a). There was an active block made with a mortar simulating the mechanical characteristics of masonry, and a passive block (steel, henceforth "dummy") to anchor the composite strip. The measurement of the load applied by the jack made the testing system statically determinate (Fig. 2b). These blocks were connected to each other by means of a compression hinge halfway up to enable the transmission of a compressive horizontal force between them (balancing the tensile horizontal force in the composite strip).

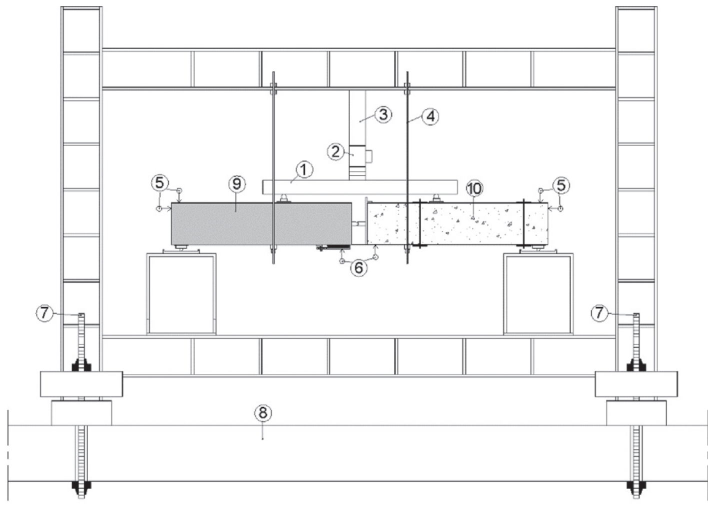
From this study, it was concluded that the strengthening solution for masonry walls (glass fibres bonded with epoxy resin) was greatly improved by the use of the confinement devices. This achieved greater mobilisation of loads by the fibres and prevented failure modes arising from the loss of bond between the reinforcing fibres and the substrate. These devices should also increase the lateral confinement of the walls and, therefore, their compressive resistance, and also enable greater deformation of the fibres.

An experimental programme was subsequently undertaken to develop the strengthening technique, specifically by replacing the composite GFRP strips with a CFRP reinforced render covering the whole side of the wall. Gomes [13], reports the results of an experimental programme involving a series of bond tests with a test setup similar to that of [11,12], which studied some hydraulic matrix solutions for the reinforced render material, with all of the mortars being manually applied (Fig. 3). This solution was found to have potential for the seismic strengthening of load-bearing masonry walls because of increased deformability, ductility and out-of-plane bending strength of such walls. This beneficial effect relied on the use of the confinement devices, which proved important to ensure bonding conditions between the masonry block (corresponding to an actual situation in a masonry wall) and the manually applied reinforcing material.

In the tests described in Proença et al. [12], the stiffness, tensile strength and shear strength of the resin were clearly higher than those of the masonry, and failure usually occurred through the material that simulated the masonry (failure location 1, Fig. 4). However, in some cases poor surface preparation led to failure occurring at the interface between the masonry and the bonding resin, or between the resin and the FRP, due to lack of adhesion at the surface (failure locations 2 and 4, Fig. 4). For the tests described in Gomes [13], collapse always happened at failure location 5 (Fig. 4), showing that there was good adhesion in terms of both strength and stiffness at the interface between substrate and reinforced render strip. It also showed that for the test conditions there was an inefficient internal bond between the mortar matrix and the carbon fibre mesh of the CFRP reinforced render. The absence of fracture failure of the carbon fibre mesh in those tests resulted essentially from the insufficient strength of the mortar matrix. The bonding conditions therefore had to be improved to ensure that the mortar matrix could maintain its cohesion functions in the composite until it reached the tensile strength limit of the carbon fibre (i.e. until failure).

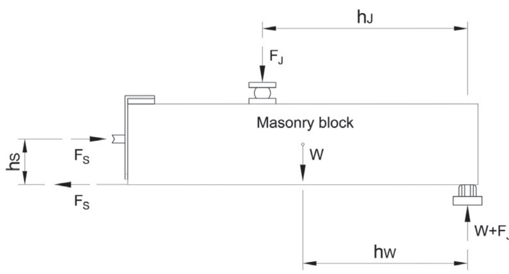
Using a reinforcement solution based on adding a CFRP reinforced render on an existing masonry wall is to some extent similar to the ComRehab system. However, some issues of special concern about the differences in implementing the strengthening process should be emphasised, because the effectiveness of this new reinforcement technique depends largely on its execution. In essence, the basic principle is still to bond strips of composite material to the masonry wall to improve its tensile (out-of-plane flexural) strength, thereby also enhancing the in-plane behaviour.

The manual application of a new structural layer of plastering mortar encountered some difficulties in ensuring good adhesion between the CFRP reinforced render and the masonry wall if the mortar was simply laid on the masonry wall. The levels of shear



1 Load distribution beam **2** Load cell **3** Hydraulic jack **4** Provisional hanging syst. **5/6** Displacement transducers
7 Dywidag bars **8** Stiff floor **9** Dummy steel block **10** Masonry block

a. Side view



$$F_S = \frac{W \cdot h_W + F_J \cdot h_J}{h_S}$$

W Weight
F_J Jack load applied to the masonry block
F_S Force at reinforcing strip

b. Free-body diagram of the masonry block

Fig. 2. Test setup [12].

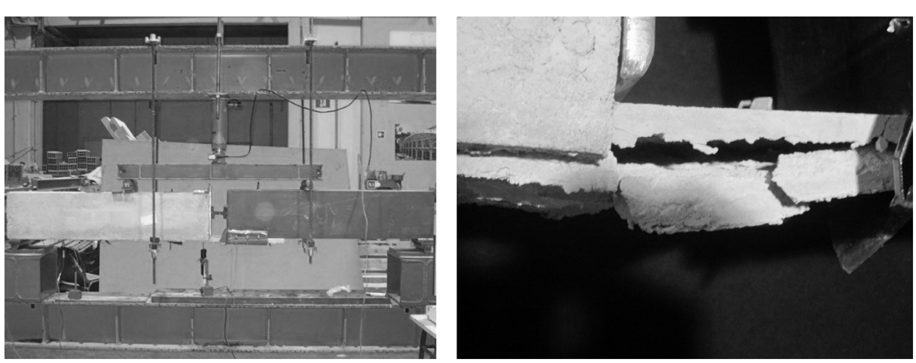
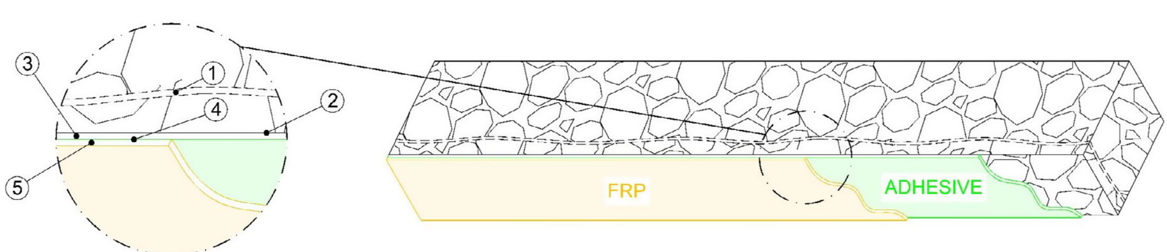


Fig. 3. Bond tests performed on CFRP reinforced render strips (manual application) [13].



1 Masonry **2** Beteween masonry and adhesive **3** Inside adhesive **4** Between adhesive and FRP **5** Inside FRP

Fig. 4. Failure modes and their location.

stress between the substrate and coating layer in cases where stresses developed throughout almost all the carbon fibre mesh were so high that they would lead to the detachment of the mortar layer. This limitation could supposedly be overcome if the bond between the masonry and the reinforcing composite material were improved by applying the coating mechanically [14–16], instead of manually, by high speed spraying, similar to shotcreting.

Another feature of the ComRehab system that was retained was the possibility of being able to use confinement devices to work in conjunction with the CRFP reinforced render, although with different objectives. While the reinforcement layer is meant to improve the mechanical behaviour of the masonry by enabling the development of the tensile strength, the confinement devices are intended to keep the reinforced render material in conditions that let it function even if the coating layer becomes detached from the masonry substrate.

3. Description of the experimental work

The experimental programme was designed to provide the basis for a subsequent calculation model (and design rules) for the application of the technique presently under development. The experimental programme adopted in the ComRehab Project was taken as a reference, adding specific tests to tackle the detailing issues that arise for this specific strengthening technique. In general, the experimental programme devised to develop this technique was divided into four distinct, yet interrelated, intervention fields, thus:

- Material characterisation tests,
- Cyclic adhesion/anchorage tests on CFRP reinforced render strips,
- Cyclic tests for in-plane horizontal loads,
- Cyclic tests for out-of-plane horizontal loads.

The characterisation tests envisaged sought to determine the main mechanical characteristics of the materials constituting the reinforcing solution as well as of the materials used in the test specimens of the subsequent laboratory work. The CFRP reinforced render strips underwent seven direct tensile strength tests (Fig. 5), each with different objectives (Table 3), namely, the assessment of the tensile strength of different strengthening materials, and the study of the effect of different anchoring details. Standard ASTM E8 procedures were followed [17].

Note that, when the experimental work started there were still serious concerns about the true ability of the CFRP reinforced render strips to bond to the masonry substrates. Thus, it was decided to test an alternative material in the direct tensile strength tests, one that could not be defined as a CFRP reinforced render because of the cementitious origin of its mortar matrix and because it did not contain a carbon fibre mesh. This material, brand name ARMOcrete, does contain fibres that give it high-performance mechanical properties. These tensile tests mechanically evaluated both the uniaxial tensile strength and Young's modulus of the reinforced render composite material strips, manually applied against their moulds.

An extensive, nearly full-scale series of tests of wall specimens (26 in number) strengthened accordingly and tested both in-plane and out-of-plane followed the experimental campaign. This large number of specimens led to the development of a test material, here called *equivalent-masonry*, developed to replicate the relevant mechanical characteristics of typical rubble stone masonry. The equivalent-masonry is a material made from river sand, rich clay sand, coarse aggregate (gravel) and hydraulic lime, acting as binder. This material differs mechanically from real masonry because of its homogeneity in contrast to the different heterogeneities, both in height and thickness, of the latter material. However, as stated before, the macro mechanical characteristics are comparable. There was an initial study on the composition of the equivalent-masonry, varying the proportion of the constituents, and the final composition had mechanical properties comparable to those of common rubble masonry.

The mortar matrix of the render reinforcing material was mechanically characterised by uniaxial compression tests and the Young's modulus was determined. For logistical reasons it was necessary to use two types of mortar to form the matrix of the reinforced render material, namely: Albaria Intonaco (produced by BASF) and Reabilita Cal (produced by SECIL). Despite the fact that both of these mortars were of the ready mixed type, there was a need to confirm to what extent the production technique (shotcrete) could change the mechanical properties of the material. Samples for each type of mortar were produced for the subsequent collection of cylindrical cores and the experimental determination of the Young's modulus, followed by the determination of the uniaxial compressive strength (Table 1).

Once the materials for the walls (equivalent-masonry) and the CFRP reinforced render strips had been characterised, the rest of the experimental work focused on the study and characterisation of the bond and anchorage behaviour, followed by the in-plane and out-of-plane behaviour of the duly strengthened masonry walls.

The cyclic bond tests performed previously [11–13], though extremely important, focused on the adhesion and intermediate anchoring, with the confinement devices, and did not address the anchorage of the end of the strip, equivalent to the anchorage at the foundation or storey level. The new testing campaign therefore also targeted the validation of the end anchorage detailing, used at

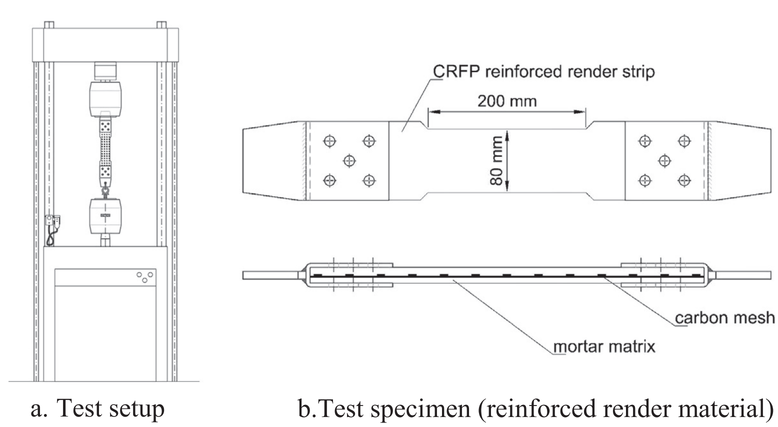


Fig. 5. Direct tensile test performed on CFRP reinforced render strips.

Table 1
Mortar matrix mechanical characterisation.

Mortar ref.	Mortar solution (Manufacturer)	Uniaxial compressive strength		Young's modulus	
		Average STRESS	Standard deviation	Average value	Standard deviation
MAP_01	Albaria Intonaco (BASF)	4.99 MPa	7.81%	0.833 GPa	1.60%
MAP_02	Reabilita Cal (SECIL)	4.62 MPa	1.16%	0.860 GPa	3.90%

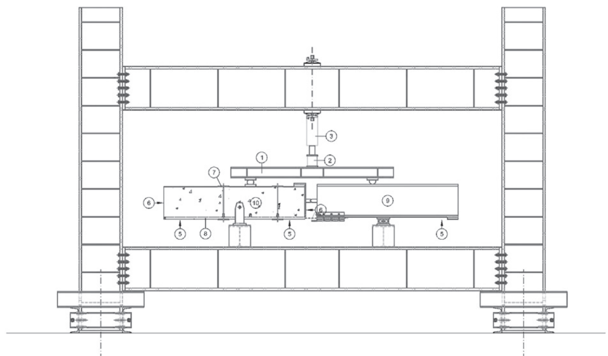


Fig. 6. Cyclic adhesion/anchorage test setup (side view).

Table 2
Cyclic adhesion/anchorage tests performed on CFRP reinforced render strips.

Sample Ref.	Mortar application	Anchorage to dummy	Carbon fibre mesh
ECA_01.01 ECA_01.02 ECA_01.03	Shotcreting	Epoxy resin in the carbon mesh, "adhesive"	80 g of carbon per m2 of mesh (S&P ARMO-mesh L200)
ECA_02.01 ECA_02.02 ECA_02.03			200 g of carbon per m2 of mesh (S&P ARMO-mesh L500)

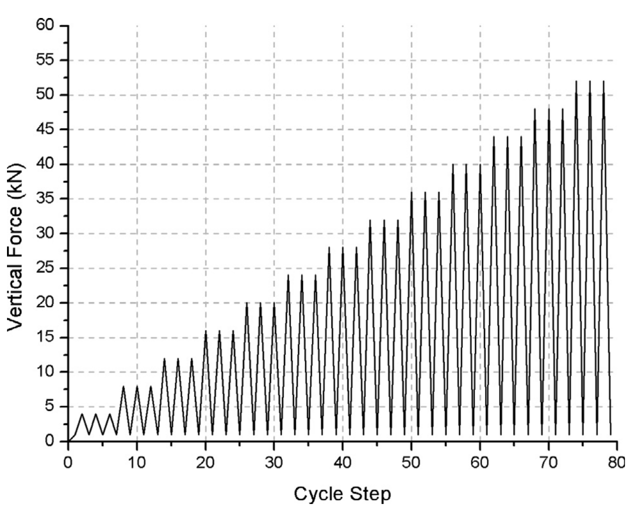


Fig. 7. Theoretical loading cycle of the cyclic bond tests (ECA_01 and ECA_02 test series).

the dummy steel block, based on the detailing used in the tensile tests of the CFRP reinforced render strips. The test setup for these adhesion/anchorage tests, schematically shown in Fig. 6, was similar to that used in Gomes [13]. Similarly to the test setup depicted in Fig. 2, the present test setup is also statically determinate, allowing for the indirect computation of the force at the reinforcing strip, albeit with a slightly different geometric configuration.

The reinforced render mortar matrix was applied by high speed mechanical spraying – shotcreting – instead of manually. In view of being able to apply the reinforcement strips in this way, two sets of three cyclic tests were conducted (Table 2). The tests differ in that a different carbon fibre mesh (with different grammage) was used in each group, while the application scheme of the reinforcing strip, the type of anchorage in the dummy block and the mortar of the matrix of the reinforced render material (Albaria Intonaco from BASF) were the same for both groups.

The tests were conducted with force control, following the loading history graphically depicted in Fig. 7. The controlling force was that applied by the hydraulic jack. The loading history was of the repeated cycle type, with downwards positive force, which in turn induced tensile-only forces in the reinforcing strip. The cycles were repeated three times for increasing amplitudes – multiples of 4 kN, approximately 2.5 kN in the reinforcing strip. The repetition of cycles and the increasing amplitude (till collapse) were considered as a way of capturing the effects of earthquake damage, namely the strength and stiffness degradation that result from large amplitude alternate cycles. A mention should be made to the fact that the test setup did not allow for reversed cyclic loading history, therefore failing to capture the cumulative damage that might have resulted from the compression of the reinforcing strip.

Once the CFRP reinforced render strips behaviour had been characterised, the subsequent experimental work focused on the in-plane and out-of-plane bending behaviour of strengthened masonry walls. The results of the experimental tests of the horizontal actions on strengthened walls will be covered in future publications.

4. Experimental results

The experimental work described in the present paper was divided into the material characterisation of the reinforcing strips, followed by the adhesion/anchorage tests on CFRP reinforced render strips.

4.1. Material characterisation tests

The test specimens had the following characteristics: ARMOcrete with 20 mm (thickness) × 80 mm (width) at the narrowest part and CFRP reinforced render with 20 mm (thickness) × 80 mm (width) at the narrowest part and 80 g/m^2 CFRP mesh (Fig. 5).

One of the critical aspects of these tests was the clamping at the ends of the specimens. Two different clamping details were studied: mechanical (indirectly bolting the specimens to the holding jaws of the universal testing machine) and another here called "adhesive", in which the test specimen was indirectly attached to the holding jaws by means of an epoxy resin. This adhesive clamping detail was further divided into two types, depending on whether the adhesive was applied over the mortar matrix or directly on the carbon fibre mesh.

Of the seven direct tensile tests, the worst results were those of the specimens whose ends were clamped mechanically, where the typical failure mode of a direct tensile test was impossible to obtain. The adhesive clamping proved to be quite reliable (failure occurred in the sample), and, in the case of the CFRP reinforced render test specimens, the test with adhesive clamping directly to the carbon fibre mesh (Table 3) was the one that gave the best results, in terms of both strength and stiffness.

These direct tensile tests gave an indication of the tensile strength of the CFRP reinforced render, as well as some valuable insight on the best clamping solution. The best clamping detail for the reinforced render was achieved with an adhesive clamping, applied between the carbon fibre mesh and the steel device anchoring the composite material. The importance of this finding was considered in the remaining experimental work, namely in the adhesion/anchorage tests and the in-plane and out-of-plane bending tests on wall specimens.

An indication of the mechanical properties (tensile strength and Young's modulus) of the reinforced render composite material can be seen in the result of test ETD_03.07, namely, 1.98 MPa for tensile strength and a Young's modulus of 392 MPa, for a 2 cm thickness of a CFRP reinforced render with an ARMO-mesh L200 armour. These values are consistent with the specifications of the CFRP mesh manufacturer (S&P). The experimental results also indicate that the Young's modulus of the ARMOcrete material is higher than that of the CFRP reinforced render and that the latter is within the range found in common rubble masonry.

4.2. Cyclic adhesion/anchorage tests

The tests on CFRP reinforced render strips required the construction of six equivalent-masonry blocks, measuring 130 cm (length) × 30 cm (height) × 20 cm (width). These blocks were prepared to receive the CFRP reinforced render strip by opening a 2 cm depth notch in each, which also allowed for roughening of the surface, exposing the gravel, of the equivalent-masonry material (Fig. 8b).

The recess of the mortar joints in a rubble masonry was simulated by opening three grooves, also 2 cm deep, and 25 cm apart (Fig. 8a). The steel confinement devices were applied at the end grooves, to improve adhesion of the CFRP reinforced render strips to the equivalent-masonry block.

The first series of tests (ECA_01) showed that the adopted anchorage and bonding solutions were suitable for the intended purposes. The CFRP mesh fracture characterised the collapse under testing (Fig. 9a). In contrast with the failure modes of the tests conducted in Gomes [13], which used the same carbon fibre mesh (ARMO-mesh L200). The results of the experimental tests carried out in Gomes [13], are explained by the limitations of the bonding solution adopted, already mentioned and mainly caused by the manual application of the CFRP reinforced render.

Damage to the strip, more precisely within the mortar, was reduced, as only small amounts of mortar detached from the equivalent-masonry blocks and at its endings (Fig. 9b). This behaviour indicated that the mortar matrix could incorporate a stronger carbon fibre mesh (higher grammage), which led us to us ARMO-mesh L500 (Table 3) in the next test series (ECA_02). In the first test series (ECA_01, Fig. 10), the mean failure force was 12.07 kN (standard deviation of 6.88%) for the strength of the strip. This average strength was computed without considering the results of specimen ECA_01.03, since its poor assemblage led to the inefficient behaviour of the anchorage to the dummy block, since only some of the carbon fibre elements were actually stretched.

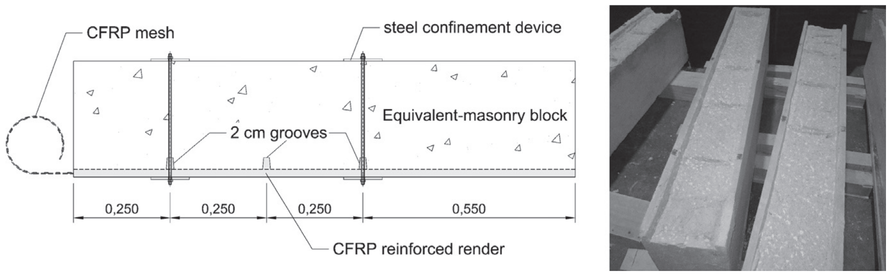
The ECA_02 test series results (Fig. 11) again demonstrate that this strengthening solution meets the objectives regarding the adhesion of the reinforcing strips both to the equivalent-masonry and to the anchored extremity. There was a significant increase in strength compared with the ECA_01 series, achieving a mean strip strength of 20.26 kN (standard deviation of 1.92%), higher (at about 69%) than the average of the maximum forces achieved in the ECA_01 series.

The damage pattern was unchanged, although there had been a large detachment of the strip at the end of the block (Fig. 12a). The low level of damage along the CFRP reinforced render strip bonded to the equivalent-masonry block indicates that the behaviour of

Table 3
Direct tensile strength tests performed on the CFRP reinforced render strips.

Test reference	Strip material	Anchorage solution	Ultimate load (kN)	Tensile strength (MPa)	Young's Modulus (MPa)
ETD_03.01	ARMOcrete	Mechanical (5 bolts per anchorage)	1.23 (*)	0.77 (*)	–
ETD_03.02	ARMOcrete	Mechanical (4 bolts per anchorage)	1.35 (*)	0.84 (*)	–
ETD_03.03	ARMOcrete	Mechanical (3 bolts per anchorage)	1.66 (*)	1.04 (*)	–
ETD_03.04	ARMOcrete	Adhesive (epoxy resin on specimen surfaces)	2.98	1.86	2132
ETD_03.05	CFRP reinf. render	Mechanical (5 bolts per anchorage)	0.18 (*)	0.11 (*)	–
ETD_03.06	CFRP reinf. Render	Adhesive (epoxy resin on specimen surfaces)	1.31 (*)	0.82 (*)	–
ETD_03.07	CFRP reinf. render	Adhesive (epoxy resin on the carbon mesh)	3.16	1.98	392

(*) Premature collapse of the tested specimen.



a. Constitution of the equivalent-masonry block b.Opened notches

Fig. 8. Cyclic adhesion/anchorage tests assemblage.

a. Fracture of the CFRP mesh (ECA_01.01) b. Reinforced render mortar detachment (ECA_01.02)

Fig. 9. Damage features of the ECA_01 specimens.

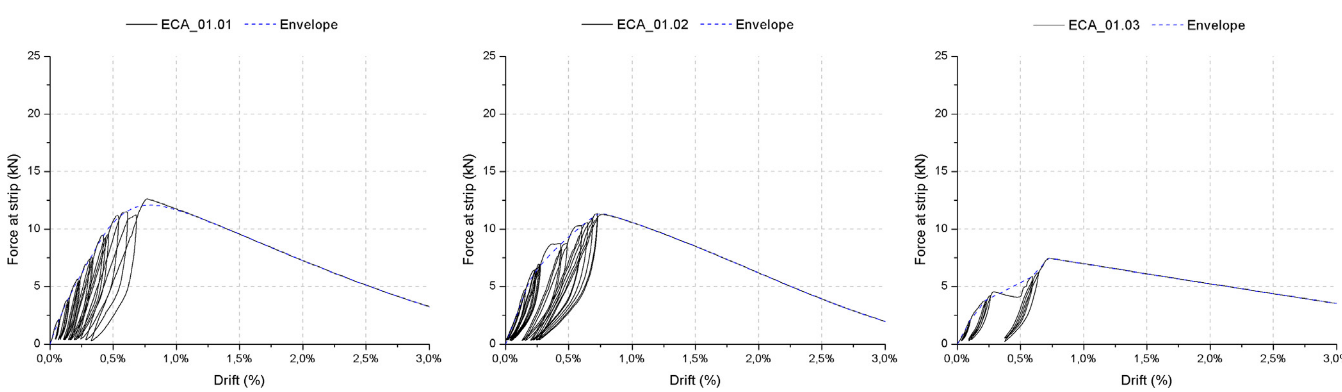


Fig. 10. Cyclic adhesion/anchorage tests results (ECA_01 series).

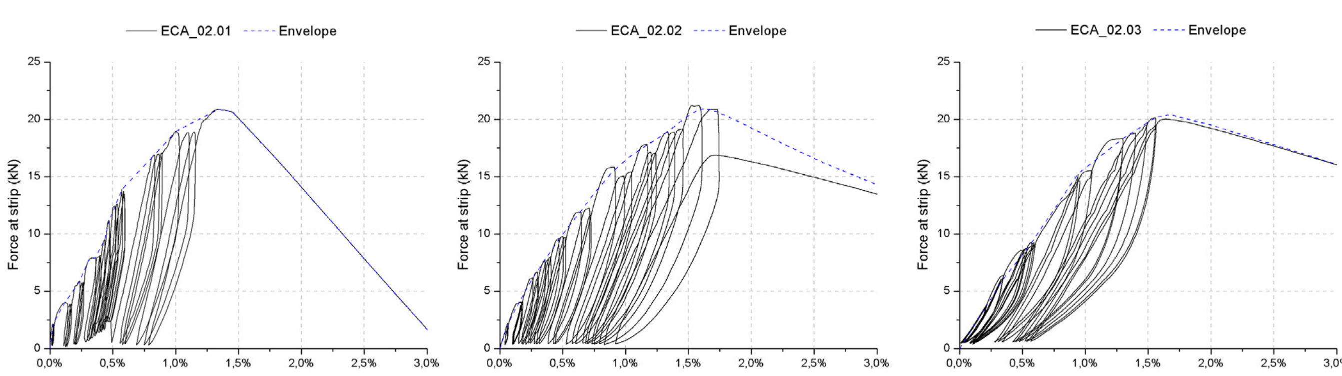


Fig. 11. Cyclic adhesion/anchorage tests results (ECA_02 series).

a. Reinforced render mortar detachment (ECA_02.03)

b. Fracture of the CFRP mesh (ECA_02.01)

Fig. 12. Damage features of the ECA_02 specimens.

the adhesion at this interface had been very close to total adhesion effectiveness. The recourse to the confinement devices seemed unnecessary, because only in the ECA_02.03 specimen did these have any influence on the capacity of the reinforcing strip to bond to the equivalent-masonry block. Even then only the device nearest to the connection of the blocks had any effect. Thus, the importance of these devices proved to be small, although their use should be considered, especially in the detailed solutions for anchoring the CFRP reinforced render strips. The fracture of the CFRP mesh was the collapse mode for all the specimens (Fig. 12b).

The cyclic tests also showed that the loading and unloading cycles did not lead to a noticeable loss of mechanical strength in the bonding of the proposed anchoring and bonding solutions (Figs. 10 and 11). The tests also demonstrated there was some energy dissipation capacity, but not enough to suggest that the use of this strengthening technique would lead to a significant increase in the energy dissipation capacity of the structure.

Finally, the assessment of the deformation (rotation) capacity of the anchoring solution is important considering that, for out-of-plane forces, the plastic hinges should be located at the base of the masonry walls [18,19]. It could be seen that for the ECA_02 series specimens the ultimate strength (corresponding to the CFRP mesh tensile fracture) occurred with a drift of about 1.5% (Fig. 13). For the ECA_01 specimens the fracture occurred with a smaller drift (of about 0.7%), which meant the ARMO-mesh L200 had a lower deformation capacity than the ARMO-mesh L500. Such deformation capacity suggests good prospects for the tests regarding the out-of-plane bending behaviour of masonry walls.

Comparing the results of the two test series (Fig. 13) it is also possible to see that the stiffness of the studied bonding solution does not seem to depend on the grammage of the carbon fibre mesh, since the overall stiffness of the connection between blocks was similar in both series.

5. Conclusions

With the completion of this experimental work, one of the stages in the development of the reinforcement technique that involves applying external layers of CFRP reinforced render was established. This stage provides the basis for defining the bonding behaviour and the anchorage solutions. The good behaviour of the studied solutions was due mainly to two factors that were taken into account in the preparation of the test specimens:

- The first involved the adhesive bonding of the reinforced render carbon fibre mesh to steel anchorage plates, intended for circumstances where structural details require the use of anchoring devices;
- The second established the bonding behaviour between the reinforced render material and the masonry substrate, characterised by good levels of adhesion between the materials, due the mortar being applied by shotcreting.

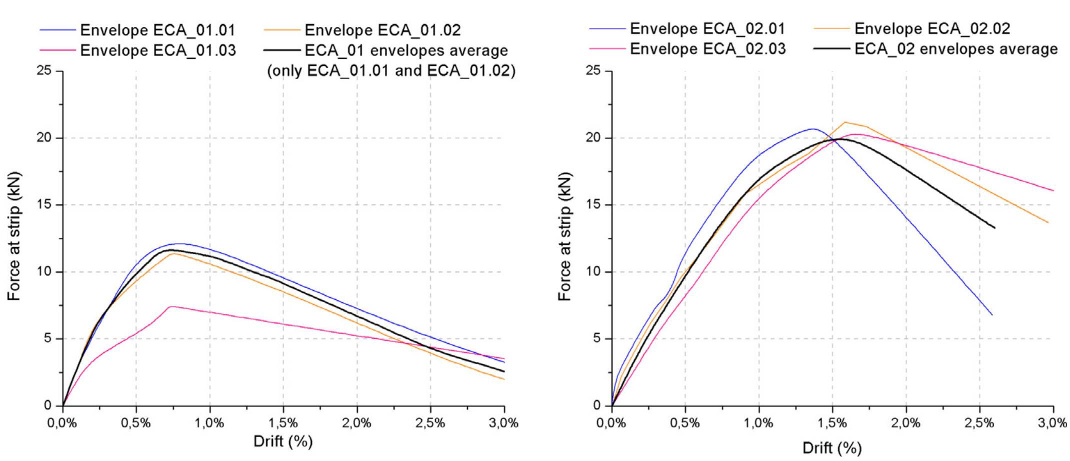


Fig. 13. Comparison between the ECA_01 and ECA_02 series.

However, the results do not explain to what extent and with what detailing (e.g., what carbon fibre mesh grammage) the increased strength provided by this reinforcing technique is proportionate to the desired seismic behaviour of old buildings. The awareness of the structural solution's mechanical abilities depends largely on the differences in strength, stiffness and ductility between non-reinforced masonry walls and similar walls that have been strengthened. Its assurance could only be established with experimental tests and numerical models that could represent real masonry walls. The results set out in the present work were the basis for other experimental campaigns (in-plane and out-of-plane test on full-scale masonry walls, the subject of future publications by the same authors) as well as for the succeeding numerical studies. This sequence of studies culminated in the establishment of calculation models to define the reinforcing abilities of the proposed technique in their main areas of application.

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