Experimental Study of Compressed Ceramic Hollow Brick Masonry Structures Strengthened with GFRP Meshes

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Abstract. The article presents the results of the experimental study of masonry columns which have been strengthened after high-level axial compression loading with glass fiber reinforced polymer composites. Preliminary damaged ceramic hollow-brick middle-scale models were continuously wrapped with Glass FRP meshes in order to the testing program. The target point of this early exploration is to define the efficiency of the described method of strengthening for considerably affected models after their decompression. The "stress-strain" curves have been compared for confined and unconfined specimens. Reported results demonstrated raised load-bearing and ductility values for confined columns. In addition, the failure mode for wrapping has been noted and described. Control samples have shown brittle failure in contrast to strengthened samples' plain collapse. Any atypical failure mode (due to sharp ceramic broken pieces) has not been observed. The paper also provides conclusions in terms of obtained experimental results and addresses numerical investigations to further research.

Keywords: Masonry columns · GFRP · Mesh · Strengthening · Confinement

1 Introduction

The external wrapping of compressed masonry structures with GFRP (Glass Fiber-Reinforced Polymer) composites becomes more popular owing to applicability in historical buildings [1] and that strengthening method's advantages (handling, growing cost-effectiveness, installation speed, low weight, high strength, etc.). A range of studies has been published in recent years aiming to give more information in this area. Thus, in the frame of recent research [2] two different series of masonry columns were confined with GFRP and CFRP strips bonded to the column with an epoxy resin. Different schemes of FRP wrapping were investigated by means of non-axial compression tests. Other scientists [3] presented experimental research for masonry columns strengthened under the vertical load. All strengthened samples were confined with GFRP straps applied in a different manner (horizontally and spirally) with various overlapping options. The authors also provided load-bearing efficiency analysis of confined columns and the impact of the existing compressive stress in a column during confinement. Some investigations [4] were dedicated to the strengthening of masonry columns with a circular cross-section, confined with glass and basalt FRP systems.

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Glass and basalt FRP composites (sheets and grids) were used with different strengthening schemes (including complete jacketing and discontinuous FRP strips) basing on different bonding type (including epoxy resin and polymer/cement-based mortar). Studies reported in paper [5] showed the outcomes of experimental tests for columns subjected to non-axial compression load. Three confinement types have been experimentally analyzed in order to evaluate and compare the effectiveness of glass FRP, carbon FRP, and basalt FRP laminates wrapping. Further investigations were performed by explorers [6] for full-scale columns using: GFRP sheets, discontinuous and continuous GFRP wrapping and internal carbon FRP bars. The experimental results were presented and compared with the results obtained from the author's experimental tests on medium scale specimens (using the same materials). Canadian scientists [7] studied steel-reinforced and plain masonry columns strengthened by spraying them with GFRP. Minor increases in strength and large increases in strain capacity were achieved with both types of columns. In addition to the mentioned above researches where it was dealt particularly with GFRP, a range of authors [8–11] reported noteworthy experimental results of masonry columns investigations with other FRP materials.

Considering the lack of studies when masonry columns are damaged significantly before strengthening, this paper presents early experimental results as a part of a more complex program meaning to research strengthened by GFRP jacketing masonry structures exposed to mechanical and temperature [12] actions under variable loading levels and materials.

2 Materials and Methods

2.1 Materials

Test Program is described briefly in Table 1. Specimens are labeled respectively to the stage of testing (without strengthening ("n"), before ("d") or after ("s") strengthening.

Table 1. Testing program

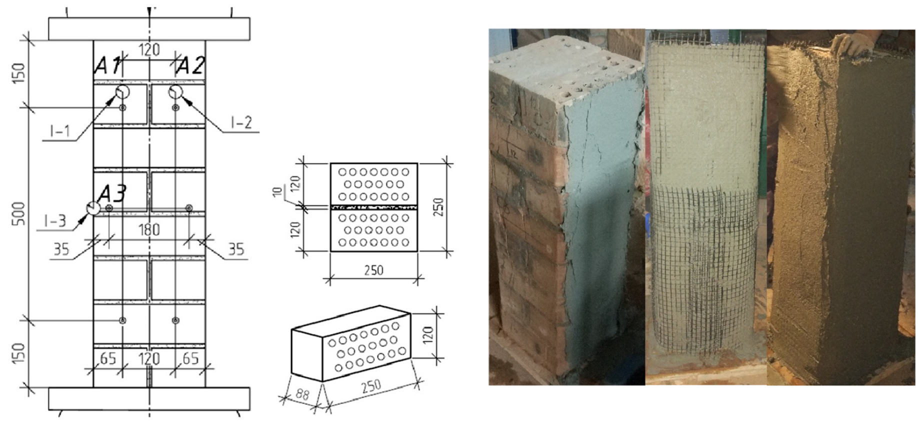
Specimen's label	Strengthening	Description
S 1n and S 2n	None	Control sample
S 1d and S 2d	None	Damaged
S 1 s and S 2 s	GFRP mesh	Strengthened after damaging

As specimen's material the hollow (volume of holes is 28%) ceramic bricks [13] were used with unit dimensions 250 mm × 120 mm × 88 mm. Bonding mortar was manufactured in-site by mixing Portland cement and sand with a mass ratio of (1:6). Lime was not used in the mortar therefore plasticizer was applied instead to improve the mortar workability. Mechanical properties were defined according to the national standards. Mortar strength was recorded by results of compression test for 28-day standard cubes 70 mm × 70 mm × 70 mm. The compression strength for bricks was received by testing bricks from series used in the specimens. Average (10 tests) compressive strength reported as f_m = 5.70 MPa for mortar [14] and f_b = 6.31 MPa for brick [15]. Reinforcing system included the glass fiber mesh [16] and two-component ready-mixed fiber-reinforced repair mortar [17]. Basing on producer's data mesh properties were taken as follows: mesh size - 12.7 mm × 12.7 mm; tensile strength – 1300 MPa; elastic modulus 72 GPa; ultimate strain – 1.8%.

For this early exploration as specimens were used four masonry square columns made by assembling bricks with mortar joints. Each brick's layer had an orthogonal direction to the top and bottom layers. The specimen's parameters was as follow: height ~800 mm, cross-section - 250 mm × 250 mm, mortar thickness - ~10 mm.

2.2 Methods

Masonry columns have been tested under axial compression provided by means of the hydraulic press (max. capacity −1250 kN). Specimens were axially loaded with a 10-min pause on every loading step to achieve full crack development and stabilization. Longitudinal and transversal deformations were measured by mechanical strain gages during compression test with tolerance 0.01 mm and 0.001 mm respectively. Gages location and test set–up scheme are represented in Fig. 1a. Two columns ("s" series) were loaded up to failure as control samples. The other two columns ("d" series) were subjected to ~80% of ultimate loading and staged for 20 min.



(a) (b)

Fig. 1. Test set-up scheme: (a) gages location; (b) reinforcing after damaging.

After that the specimens were unloaded and confined with continuous GFRP-mesh wrapping. Preparation and strengthening application procedure was realized in accordance with producer recommendations. All surfaces were cleaned carefully to ensure good adhesion. External column's corners were rounded (r ~ 20 mm) to avoid mesh cutting and stresses concentrating. When the first layer of repair mortar (~5 mm) was applied the fiber-glass mesh (2 layers) was placed and pressed down into mortar while it was still wet. The mesh was lightly smoothed with respect to mortar adhere considering overlapping in strap joints due to product technical sheets. Reinforcing mesh has been completely covered with the second layer of repair mortar with the same thickness as the first one (Fig. 1b).

3 Results and Discussions

3.1 Control Samples

Specimens within "n" series (see Table 1) have been assumed as control samples and were tested without any reinforcing in aim to define columns' ultimate strength experimentally. Since ceramic bricks (which tend to rapid deconstruction) were used in this masonry, hereinafter the first macro crack occurrence was accepted as the failure start point. Owing to material peculiarities this moment could be easily defined from "stress-strain" diagram (Fig. 2) at the point where curve slope changes sharply. Longitudinal strains were measured for each column's side (labeled "A", "B", "C", "D"), consequently macro crack developing was controlled not only visually but analytically as well.

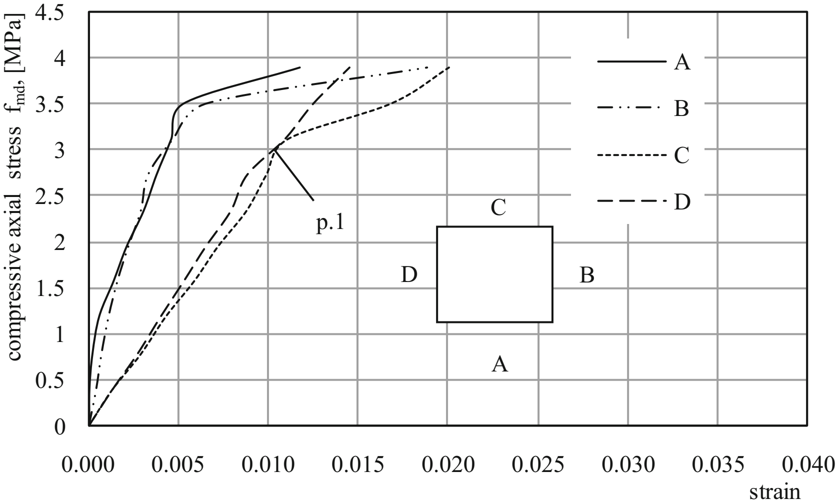


Fig. 2. Experimental "stress-strain" diagram for unconfined specimens ("n" series)

As shown above the maximum stress value reached f_{max} = 3.8 MPa. The ultimate stress was noted as f_{md} = 3.02 MPa ($\sim$0.79 f_{max}) which was confirmed by macro crack rising on side "C" (see p. 1 on Fig. 2). At 0.9 f_{max} loading level cracks widely spread through other faces ("A", "B") thus model's brittle failure followed up. The strain value for the ultimate stress level was reported as ε_{md} = 0.010.

Using f_{md} value as control compressive strength target loading level for the next series ($f_{0.8md}$ = 2.4 MPa) has been obtained. Specimens included to “d” series were subjected to this compressive loading due to the testing program. To justify such an approach and to avoid using samples with significantly different mechanical properties “stress-strain” curves for these two series (“n” and “d”) were compared (Fig. 3). Related curves were similar thus it could be stated that further reference between those two series is reasonable. After specimens’ unloading crack patterns for each column’s side were investigated Fig. 4.

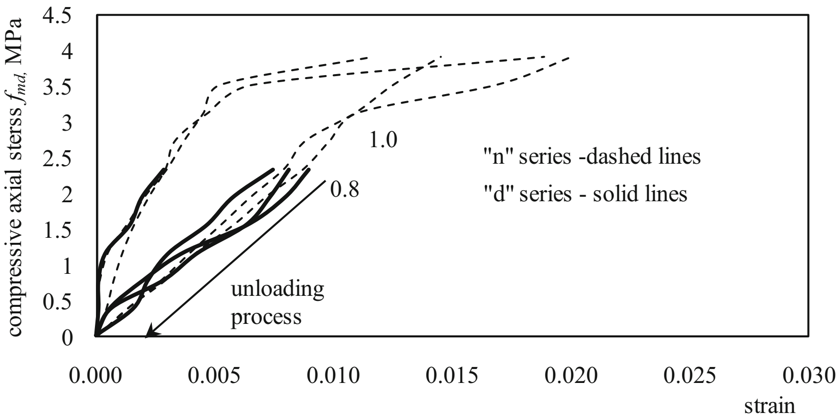


Fig. 3. Experimental “stress-strain” diagram for unconfined specimens (“d” series)

After columns strengthening by applying methods described in Sect. 2.2 specimens were considered as “s series” and the new tests for these confined models were performed (Fig. 5). No significant cracking in repair mortar was not observed up to level f_{mcd} = 2.5 MPa. After passing this stage the first initial cracks were detected (~0.1 mm) with plain developing till the stress level f_{mcd} = 3.52 MPa. This level overstepping was marked by the cracking process with openings up to 0.3 mm and confinement mortar crumpling as well. At the maximum stress level f_{mcd} = 4.2 MPa samples’ collapse (caused by GFRP mesh tensile rupture) has occurred.

Curve’s slope changing relates to the macro crack occurrence in the repair mortar surface (see p. A in Fig. 5). Following the previous assumption it was treated as ultimate strength level f_{cmd} = 3.52 MPa. Ultimate strain for confined series was adjusted as ε_{cmd} = 0.013. For stress analysis given above (see Fig. 2, Fig. 5) the mean value for twins-samples in each series was used. Variation coefficient for “n” and “s” series was 8.13% and 7.14% respectively.

The model’s appearance after testing is presented in Fig. 6. Strengthened samples had been showing slow and plain damage process until the moment when confinement lost integrity. Mesh rupture started in the most concentrated zones near to the column’s corners following jacket mortar separating initiated from the sample’s mid-height (Fig. 6). Subsequently, the failure process progressed more sharply due to no

Fig. 4. Crack patterns after damaging by axial loading

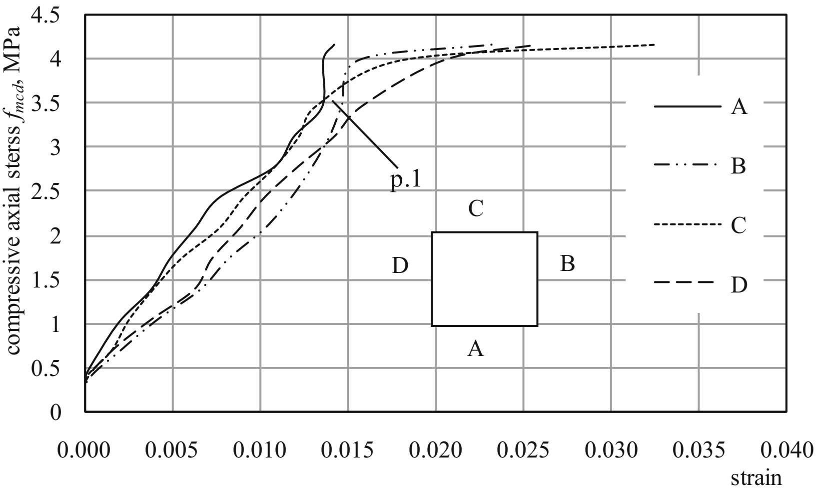


Fig. 5. Experimental "stress-strain" diagram for confined specimens ("s" series)

Fig. 6. Failure mode and appearance of strengthened specimens

restrictions for abandoned masonry core expansion. Such kind of failure mode was typical for all specimens.

4 Conclusions

This paper presents the results of investigation for confined middle-scale masonry structures produced with hollow ceramic bricks after subjecting to a high level (up to 80% of ultimate strength) compression. Strengthening with GFRP meshes was provided after models' decompression. Provided early research draws to some conclusions listed below. Initially, a significant strengthening effect due to the level of preliminary damages and applied type of GFRP mesh was not expected. And obtained results confirmed that in a numerical manner. Thus, according to test data, GFRP jacketing demonstrates values of normalized ultimate stress f_{cmd}/f_{md} = 1.15 and ultimate axial strain $\varepsilon_{cmd}/\varepsilon_{md}$ = 1.3. Generally, jacketed models presented more uniform models' deformation. This study shows that despite full samples' unloading GFRP-mesh applying could be not suitable enough for such a "damages-materials" combination and leads to more efficient strengthening techniques or materials (e.g. CFRP or BFRP) in terms of reasonable repairing approach. However, high-level preliminary loading was not dramatic and, finally, the strengthening effect was still reported.

Further research will be addressed to numerical analysis of obtained results and studies with different pre-loading levels as well.

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