Influence of Superficial Strengthening with FRCM System on Compressive Strength of Cracked AAC Masonry

Lukasz Drobiec¹, Wojciech Mazur¹, Remigiusz Jokiel²

¹Silesian University of Technology, Department of Building Structures, Akademicka 5 Street, 44-100 Gliwice, Poland
²BUDINŻ PB Sp. z o.o. Sp.k. Niedobczycka 2 Street, 44-290 Jejkowice, Poland

wojciech.mazur@polsl.pl

Abstract. This paper describes results from studies on effects of superficial strengthening with FRCM system on compressive strength of autoclaved aerated concrete (AAC) masonry. Tests were carried out on models with one vertical crack and without crack. The research program included walls without any strengthening, strengthened at two or four sides. In addition, models with additional anchorage of superficial strengthening by steel plates were tested. Strengthened masonry did not demonstrate an increase of compressive strength and deformability. Increased deformability was observed for circumferentially strengthened masonry.

1. Introduction

Surface reinforcements are one of the most common methods of strengthening reinforced concrete and masonry structures [1-5]. These methods were the subject of many experimental studies around the world, also at the Faculty of Civil Engineering of the Silesian University of Technology [6-8]. Usually, reinforced but undamaged wall models were subjected to experimental tests. Therefore, the aim of the presented research was to determine the actual impact of FRCM reinforcement on the load-bearing capacity of weakened models of walls made of autoclaved aerated concrete (AAC). Walls weakened by incision without reinforcement and strengthened, as well as walls without weakening and circumferentially strengthened were examined.

2. Tested models

All research models of walls were built of autoclaved aerated concrete masonry elements 180 mm wide, 590 mm long and 240 mm high, with a standard compressive strength of \( f_{bc} = 4.0 \) N / mm² and a density class of \( \rho_v = 600 \) kg / m³. The brand system, factory-prepared, thin-layer mortar with a compressive strength \( f_{m} = 6.1 \) N / mm² was used. The blocks had a tongue and a groove on the face surfaces, therefore the vertical (butt) joints were not filled with mortar.
The research models had the width of two wall elements and the height of 5 elements, and their dimensions met the requirements of the standard [9]. The dimensions of the test pieces are shown in Figure 1a, and a view of several test pieces made is shown in Figure 1b and 1c.

After 28 days from erecting, some of the models were incised to create a forced crack and then strengthened. The PBO-MX GOLD MU-RATURA system mortar was applied to the side surfaces of the reinforced models and the PBO-MESH GOLD 70/18 mesh was embedded in it, and then top layer of the PBO-MX GOLD MURATURA system mortar was applied.

The research program included four series of research elements, each of which contained three walls. In the first series, marked as S1NR, walls with a crack without reinforcement were examined. The second series, marked as S1NF2R, included scratched walls reinforced on two sides. In the third series with the symbol S1NF2RP, the walls were tested identical to those in the second series with additional mechanical anchorage of surface reinforcement. The last, fourth series with the S1NF4 designation included walls without scratching, but reinforced on all four sides.

For mechanical anchoring, flat bars with dimensions of 60x12x1100 mm with five holes drilled with a diameter of 18 mm with a 240 mm spacing were used. The flat bars are made of S355 steel and twisted with M16 threaded rods of 4.8 class steel.

The test stand and testing technique
Walls without reinforcement were tested 28 days after building, and models with reinforcement 28 days after applying the reinforcement. All elements were tested in a testing machine with a range of 200 T. Before testing, the S1NR series test models were incised with a hand saw imitating a vertical scratch running from the upper edge to 1/3 of the test model's height (Figure 2). In the S1NF2R and S1NF2RP series models, a similar incision was made before applying the reinforcement.

During the test, the load and vertical and horizontal displacements were recorded using inductive sensors with an accuracy of 0.002 mm and an automatic measuring station. Additionally, deformation was recorded using a non-contact displacement measurement system. The dimensions of the base length for wall displacement measurements have been increased by 20 mm in relation to the recommendations contained in the PN-EN 1052-1 [A2] standard in order to avoid fixing steel frames in the wall joints. The view of the research models of the S1NF2R and S1NF2RP series in the test stand is shown in Figure 3.
Figure 2. A view of models of series S1NR-1 before tests: a), b) during incising, c) with crack

Figure 3. A view of models in test stand before tests of series: a) S1NF2R-1, b) S1NF2RP-1, c) S1NF4-1

4. Test results
Table 1 shows the values of the stress at which the test pieces were scratched, the compressive strength, the modulus of elasticity and the Poisson's ratio. The values of the tearing and breaking stresses were determined by dividing the force by the measured cross-sectional area of the test piece. The values of the modulus of elasticity and Poisson's ratio were determined as the secant of the mean value of strains obtained from the measuring sensors at the stress equal to 1/3 of the maximum stress.
| Name of series | Cracking stress. kN | Destructive stress. kN | Modulus of elasticity. N/mm² | Poisson's ratio |
|---------------|---------------------|------------------------|----------------------------|----------------|
|               | per model average   | per model average      | per model average          |                |
| S1NR          |                     |                        |                            |                |
| Wall cracked  |                     |                        |                            |                |
| without       | S1NR-1              | 2.97                   | 2.98                       | 2091           | 1.04           | 3.57           |
| strengthening | S1NR-2              | 3.15                   | 3.21                       | 8066           | 7.00           |
|               | S1NR-3              | 2.57                   | 2.89                       | 3258           | 2.68           |
| S1NF2R        |                     |                        |                            |                |
| Wall cracked  |                     |                        |                            |                |
| with two-side | S1NF2R              | 3.18                   | 3.30                       | 2002           | 0.25           | 7.25           |
| strengthening | S1NF2R              | 2.84                   | 3.09                       | 19420          | 13.15          |
|               | S1NF2R              | 2.90                   | 3.11                       | 15762          | 8.34           |
| S1NF2RP       |                     |                        |                            |                |
| Wall cracked  |                     |                        |                            |                |
| with two-side | S1NF2R              | 2.97                   | 2.99                       | 16359          | 11.87          | 9.17           |
| strengthening | S1NF2R              | 2.86                   | 3.06                       | 7608           | 5.05           |
| and steel    | S1NF2R              | 2.92                   | 3.25                       | 16477          | 10.59          |
| anchorage     | P-1                 |                        |                            |                |
|               | P-2                 |                        |                            |                |
|               | P-3                 |                        |                            |                |
| S1NF4         |                     |                        |                            |                |
| Wall with     | S1NF4               | 2.45                   | 2.74                       | 2245           | 0.20           |
| four-side     | S1NF4               | 2.70                   | 3.09                       | 2308           | 0.23           |
| strengthening | S1NF4               | 2.50                   | 2.79                       | 2036           | 0.35           |
|               | P-1                 |                        |                            |                |
|               | P-2                 |                        |                            |                |
|               | P-3                 |                        |                            |                |

Based on the measurement of vertical deformations, a graph of the dependence of vertical stress $\sigma_y$ - vertical deformation $\varepsilon_y$ was determined, and based on the measurement of horizontal deformations, the Poisson's ratio $\nu$ of the wall was determined. Figure 4 shows the dependencies $\sigma_y - \varepsilon_y$, $\sigma_y - \varepsilon_x$ obtained for all test series.
Figure 4. Stress $\sigma_y$ - vertical strain $\varepsilon_y$ and horizontal strain $\varepsilon_x$ relationships for series: a) S1NR, b) S1NF2R, c) S1NF2R, d) S1NF4.

The unreinforced models of the S1NR series were damaged by vertical scratches passing through the masonry elements, as well as splitting the masonry elements and detaching the face fragments (Figure 5a). In the case of the models of the S1N2R series reinforced on both sides, the destruction effects were visible in the form of vertical scratches on the side, unreinforced wall surface (Figure 5b) or by scratching and bulging the reinforced surface at the level of the two lower layers of masonry elements (Figure 5c). No scratches were observed on the reinforcement surface in the place of the forced scratch.

Figure 5. A view of models after tests. Model of series: a) S1NR, b) S1NF2R, c) S1NF2R

In case of reinforced models with additional mechanical anchoring (S1NF2RP series), scratches were formed on the reinforcement surfaces reflecting the course of joints in the wall (Figure 6a). The all-around reinforced models were scratched in the lower part of the wall (Figure 6b) in the same way as the S1F2R series models. The research models were destroyed as a result of the exhaustion of the strength of the masonry elements. The surface reinforcement mesh was detached with the cellular concrete layer. No fiber breakage of the reinforcement mesh was recorded in any of the tested reinforced models (Figure 6c). There was also no excessive chipping of the cement matrix.
5. Analysis of test results

In models of the S1NR series, the average destructive and cracking stresses were 3.03 MPa and 2.90 MPa, respectively, as well as the Young's modulus of 4472 MPa and the Poisson's ratio of 3.57. Through the use of surface reinforcement in the models of the S1NF2R series, the cracking stress of 2.97 MPa and the breaking stress of 3.09 MPa were obtained, which were respectively 2% higher than the results of the models without reinforcement. In the models of the S1NF2RP series, the breaking stress was achieved equal to 3.06 MPa and the breaking stress, almost identical to the result of the S1NF2R series, was 3.10 MPa and higher by 2% than the breaking stress in the S1NR series. The hoop reinforcement used in the models of the S1NF4 series did not increase the load-bearing capacity of the research models, because the obtained average breaking stresses at the level of 2.87 MPa were 5% lower than in the case of the models of the S1NR series, tested as unreinforced and additionally scratched, and the scratching stresses equal to 2.55 MPa were also smaller. do not allow for drawing reliable conclusions due to the too large dispersion of the obtained values. The results of models of S1NF4 series were lower than results of series S1NR. The courses of the dependence $\sigma_y - \varepsilon_y$, $\sigma_y - \varepsilon_x$ averaged within the test series are presented in Figure 7.

![Figure 6](image6.png)

**Figure 6.** A view of models after tests. Model of series: a) S1NF2RP, b) S1NF4, c) S1NF4

![Figure 7](image7.png)

**Figure 7.** Stress $\sigma_y$ - vertical strain $\varepsilon_y$ and horizontal strain $\varepsilon_x$ relationships averaged for each series
6. Conclusions
None of the methods used to strengthen the research models had a significant effect on the increase of the load capacity of the research models. In the case of models weakened by cracks, the increase in load capacity in the S1F2R series elements reinforced on both sides, and in the S1F2RP series with additional mechanical anchorage in the form of steel elements was only 2%. The greater impact of the applied reinforcement was noted when the level of scratch stresses were increased by 3% in the S1NF2R series but was equal in the S1NF2R series models to S1NR series. The results of models of S1NF4 series were lower than results of series S1NR. do not allow for drawing reliable conclusions due to the too large dispersion of the obtained values.

Undoubtedly, more effective application of surface reinforcement will occur in the case of masonry structures subjected to tension or shear, which will be verified in a further stage of tests carried out in accordance with the standards [10, 11] and also on silicate masonry elements.

References
[1] F. Ceroni, and P. Salzano, "Design provisions for FRCM systems bonded to concrete and masonry elements", "Composites Part B: Engineering", Vol. 143, p. 230-242, 2018.
[2] S. Babaeidarabad, D. Arboleda, G. Loreto, and A. Nanni, "Shear strengthening of un-reinforced concrete masonry walls with fabric-reinforced-cementitious-matrix", "Construction and Building Materials", Vol. 65, p. 243-253, 2014.
[3] A. Bilotta, F. Ceroni, E. Nigro, and M. Pecce, "Experimental tests on FRCM strengthening systems for tuff masonry elements", "Composites Part B: Engineering", Vol. 129, p. 251-270, 2017.
[4] F.G. Carozzi, C. Poggi, A. Bellini, T. D’Antino, G. de Felice, F. Focacci, L. Holdys, L. Laghi, E. Lanoye, F. Micelli, and M. Panizza, "Experimental investigation of tensile and bond properties of Carbon-FRCM composites for strengthening masonry elements", "Composites Part B 128, pp. 100-119, 2017.
[5] R. Jokiel, and Ł. Drobiec, "Projektowanie wzmacnień konstrukcji murów mżowych systemami FRCM w świetle badań i zaleceń normowych" insulation, pp. 90, 92-94, 2019 (in Polish).
[6] J. Kubica, and M. Kaluża, "Diagonally compressed AAC Block’s masonry – effectiveness of strengthening using CRFP and GRFP laminates", Proceedings 8th International Masonry Conference, Masonry (11), Ed. by W. Jäger, B. Haseltine & A. Fried, 419-428, Dresden 2010.
[7] M. Kaluża, J. Kubica, "Behaviour of unreinforced and reinforced masonry wallets made of ACC blocks subjected to diagonal compression", Technical Transactions - Civil Engineering 1-B/2013 (2013) 79-94.
[8] M. Kaluża, I. Galman, J. Kubica, and C. Agneloni, "Diagonal Tensile Strength of AAC BlocksMasonry with Thin Joints Superficially Strengthened by Reinforced Using GFRP Net Plastering", Key Engineering Materials 624, 363-370, 2015.
[9] PN-EN 1052-1:2000 Methods of test for masonry - Part 1: Determination of compressive strength, 2000.
[10] ASTM E519-81 Standard Test Method for Diagonal Tension (Shear) of Masonry Assemblages.
[11] PN-EN 1052-3:2004 Methods of test for masonry - Part 3: Determination of initial shear strength, 2004.