Research Of Influence of Horizontal Reinforcement on Compression and Shear Strength of Autoclaved Aerated Concrete Masonry

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Abstract This paper presents a research of influence of horizontal reinforcement on compressive and shear strength of Autoclaved Aerated Concrete (AAC) masonry. Specimens were tested according to guidelines of EN 1052-1 and ASTM ES519-81 code in case of compression and shear test respectively. Reinforcement in the form of strips of mesh rolled out from a roll, consists of steel cords with an interwoven fiberglass roving was used. The influence of this type of reinforcement was also compared with the results of tests of AAC masonry walls without reinforcement, reinforced with truss type reinforcement and reinforced with synthetic mesh respectively.

1. Introduction

The adequate selection of masonry units, the type of mortar and joints provide the optimum strength parameters of walls. However, if the strength parameters still do not meet the required level, then the use of reinforced concrete elements or reinforcement should be considered. The second solution does not introduce significant changes to the wall structure and its construction. Therefore, there is a constant need for improving reinforcement for walls. According to the tests [1], the end effect of improved parameters had an impact not only on the reinforcement, but also on the method of its placing in joints.

Steel reinforcement in bed joints is usually made of ordinary rebars placed in joints filled with ordinary mortar or in chases. This option is difficult in the realization for thin joints, for which steel plane truss is used. This type of reinforcement is transported and placed in the masonry in the form of elements of a specified length. The application of carpet reinforcement made of steel is another option. Consequently, the number of reinforcement laps is reduced, and its transport and method of application are easier. However, the reinforcement selection should be mainly determined by its impact on the strength parameters of walls. The performed tests [2] also demonstrated advantages of non-metallic reinforcement in bed joints. This type of reinforcement has not yet been permitted for use by the EC6 [3], and it is difficult to verify its presence in bed joints of the complete wall [4]. This paper compares the effect of steel reinforcement mesh, which combines the features of metallic and non-metallic reinforcement, steel truss reinforcement and synthetic mesh.
2. Test models, testing technique

All models used for testing compressive and diagonal compressive strength were prepared in the same way. They were composed of masonry units \((f_{ck} = 4.0 \text{ N/mm}^2)\) with dimensions \(595 \times 240 \times 180 \text{ mm (l_u \times t_u \times h_u)}\) and thin joint mortar of class M5 \((f_{cm} = 6.1 \text{ N/mm}^2)\). The test models are shown in figure 1.

Three types of reinforcement were used to strengthen bed joints. The first option includes the Murfor Compact A-80 reinforcement on a roll, which is a mesh consisting of steel cords with an interwoven fiberglass roving. There are 14 cords made of galvanized steel. The cross-sectional area of transverse reinforcement is \(14 \times 0.69 \text{ mm} = 9.66 \text{ mm}^2\). The applied steel has characteristic yield strength \(f_{yk} = 1770 \text{ MPa}\) and modulus of longitudinal strain \(E = 180 \text{ GPa}\). The mesh is 80 mm wide.

![Figure 1](image1.png)

**Figure 1.** View of tested models: a) arrangement of masonry units, b) in laboratory

In the second case, the models of series RL-S-Z1-4-6 were strengthened with a steel truss of Murfor EFZ/Z 140 type. Chords are composed of flat bars (design strength of steel \(f_{yk} = 685 \text{ N/mm}^2\)) of cross-sectional area \(1.5 \times 8 \text{ mm}\), and diagonal members are made of smooth rebars of 1.5 mm in diameter. The total cross-sectional area of transverse reinforcement is 26.5 mm².

Plastic mesh with pitch size 5 x 5 mm was used to strengthen the models of series S1ZSt. The mesh wrap composed of single strands (approximated rectangular cross-section 1.5 mm × 0.22 mm = 0.33 mm²) was alongside the wall length, and its weft is composed of two strands (cross-section of each close to the circle of ca. 0.3 mm in diameter and total cross-sectional area equal to 0.141 mm²). The employed reinforcement is shown in figure 2.

![Figure 2](image2.png)

**Figure 2.** Employed reinforcement

Based on the experiments described in the paper [1], the reinforcement was laid in mortar placed between the masonry units. Then, mortar was placed on the bottom surface of another course of the masonry units which were placed on bed joint with the reinforcement. This technique caused that the whole reinforcement was completely surrounded with mortar. In case of the test models without reinforcement, mortar was traditionally placed only on the upper support surface of the masonry units.

The test element was marked with the letter S1 denoting the walls built with thin joint mortar with unfilled head joints, next symbols specify the type of used reinforcement, and then the number of the test element. The test elements without reinforcement were marked with the capital letter N, the truss reinforcement was marked with the letter Z1, ZSt was used for the plastic mesh, and ZM for the steel mesh. The test models subjected to diagonal compression were additionally marked with the prefix RL.
Figure 2. Structural reinforcement used in tests: a) steel mesh Murfor Compact A-80, b) steel truss of EFZ 140/Z 140 type, Legend 1 – truss chord, 2 – diagonal member, c) plastic mesh, Legend 1 – weft, 2 - wrap

All the walls were tested after at least 28 days from the date of their preparation. The compressive strength tests were performed in a hydraulic press with a working capacity of 200T in accordance with the standard PN-EN 1052-1 [5]. A dynamometer with an accuracy of 0.001 kN was used to measure compressive force during the tests. Vertical and horizontal displacements were also measured using horizontal and vertical linear variable differential transducers with an accuracy of 0.002 mm. Additionally, strains in the selected series were observed using the Digital Image Correlation System ARAMIS. The strains were measured using the reference frames with a length of 620 mm. A selected test model and the reference frames are shown in figure 3a. The testing procedure and the results are described in details in the papers [1, 6].

The tests on diagonal compressive strength were performed in a specially designed test stand in accordance with the standard ASTM E519-81 [7]. Load was applied during the tests by means of the hydraulic actuator, and the force was measured using two coupled electro-resistant dynamometer (each of an operating range of 100 kN). Vertical and horizontal displacements were measured using the linear variable differential transducers with an accuracy of 0.002 mm, which were fixed to the steel reference frames of 932 mm in length, placed along diagonals of the models. Also, the non-contact system ARAMIS for measuring strains was used in some models. The tests and the results are described in details in the papers [1, 8]. Based on trigonometric relationships for strains in the reference frames,
values of shear stresses $\tau_{ij}$, and the angle of shear strain $\gamma_i$ were determined. An example of the model at the test stand is shown in figure 3b.

![Figure 3a](image1.jpg) ![Figure 3b](image2.jpg)

**Figure 3.** View of tested models in test stand for: a) axial compression, b) diagonal compression

3. **Results and discussion**

3.1. Walls under axial compression

The unreinforced models (series S1N) under axial compression demonstrated cracks in the face plane and local debonding of their fragments.

Cracks in the walls reinforced with the steel mesh (series S1ZM) were present just before the failure of the test models. The cracks were running through joints and masonry units. Also, spalling of face fragments of masonry units was observed. The vertical cracks at the unit depth were covering the entire length of the test models (also splitting of blocks was noted). However, the cracks did not damage the reinforcement.

The units reinforced with the steel truss had more damages on lateral sides (along the wall depth) and many cases of debonding on facing were noticed.

On the other hand, the models reinforced with the mesh had more cracks on facing and occasional cracks on lateral sides. The selected test models from all series after the failure are shown in figure 4 and 5. Comparison of the results and the diagram presenting $\sigma_y - \epsilon_y$ and $\sigma_y - \epsilon_x$ relationships are illustrated in figure 6.
Figure 4. View of destroyed models in series S1-ZM: a) S1-ZM-1, b) S1-ZM-2, c) S1-ZM-3

Figure 5. View of destroyed models in series: a) S1N, b) S1-ZK-1, c) S1-ZSt
3.2. Walls subjected to diagonal compression

Cracks in the models subjected to diagonal compression appeared directly before achieving the maximum load (Figure 8). The cracks ran through bed and head joints. The cracks in the masonry units were only observed in places of supporting the models on steel fittings. No damage to steel reinforcement mesh or plastic mesh was observed in the cracked joints. The masonry units reinforced with the trusses were an exception as at first cracks in the masonry units were observed. And then, the loss in adhesion between the masonry units and the mortar occurred. The selected test models from series RL-S-ZM after the failure are shown in figure 7. Comparison of the results and the diagram presenting $\sigma$ – $\theta$. 

Figure 6. Results from compression tests on walls: a) average relationship $\sigma$ – $\varepsilon$, b) comparison of values of cracking and failure stress
Figure 7. View of destroyed models in series RL-S-ZM: a) RL-S-ZM-1, a) RL-S-ZM-3

Figure 8. Results from diagonal compression tests on walls: a) relationship $\tau - \Theta$, b) comparison of values of cracking and failure stress
3.3. Analysis of test results
The positive impact of the reinforcement on the increasing values of cracking stress was found in the axially compressed models, regardless of the type of employed reinforcement. In case of the models reinforced with steel mesh, cracking stresses contributed to 96% of the failure stress and were higher by 19% than the cracking stresses in the unreinforced walls. In other tests series, the cracking stresses contributed to 91% and 85% of the failure stress, and were higher by 21% and 10% respectively in the walls of series S1Zk and S1ZSt than the values determined for the unreinforced walls. The steel truss and plastic mesh reinforcement employed in the models of series S1ZK and S1ZSt resulted in an increase in the failure stress by 5% and 2% respectively when compared to the unreinforced models. The failure stress in the models reinforced with steel mesh was lower by 2% compared to the unreinforced models. The positive impact of the reinforcement on the increasing values of cracking stress in the diagonally compressed models was only observed in the walls with the truss reinforcement. The cracking and failure stresses were higher by 25% and 37% respectively when compared to the unreinforced models. In the masonry units reinforced with the mesh, the cracking stress contributed to 93% of the failure stress and was lower by 21% compared to the models of series S1N. These values were 97% and 35% respectively in the models reinforced with synthetic mesh. And the failure stress was lower by 16% and 34% when compared to the unreinforced models.

Table 1 presents average values of cracking and failure stresses for each series of the models subjected to axial compression \( \sigma_{cr,mv} \), \( \sigma_{u,mv} \) and diagonal compression \( \sigma_{cr,ml} \), \( \sigma_{u,ml} \). Additionally, the effect of the employed reinforcement with reference to the unreinforced models is demonstrated by comparing the results for the unreinforced and reinforced models subjected to compression \( \sigma_{u,S1Zi} / \sigma_{u,S1N} \) and diagonal compression \( \sigma_{u,RL-S-Zi} / \sigma_{u,RL-S-N} \).

### Table 1. Average value of results for test models under compression and diagonal compression.

| Series | Cracking stress \( \sigma_{cr} \) N/mm\(^2\) | Failure stress \( \sigma_u \) N/mm\(^2\) | \( \sigma_{u,S1Z} / \sigma_{u,S1N} \) | Diagonal compression |
|--------|---------------------------------|---------------------------------|--------------------------------|---------------------|
|        |                                  |                                 |                                |                     |
| S1N    | 2.35                            | 2.97                            | .                             | RL-S-N              |
| S1ZM   | 2.79                            | 2.91                            | 0.98                          | 0.192               |
| S1ZK   | 2.85                            | 3.12                            | 1.05                          | 0.153               |
| S1ZSt  | 2.59                            | 3.03                            | 1.02                          | 0.241               |

4. Conclusions
The cracks in the compressed models were observed when compressive stress reached the level of 79÷96%. The truss reinforcement improved the wall strength by 5%, and the plastic mesh reinforcement improved the wall strength by 2%. A drop in the wall strength by 2% was noticed in the walls reinforced with the steel mesh.

Considering the walls subjected to diagonal compression, the only positive impact of the reinforcement was observed for the walls with the truss reinforcement as the cracking and failure stresses increased by 25% and 37% respectively. The cracking and failure stresses in the models reinforced with the mesh were higher compared to the models reinforced with the synthetic mesh, but lower by 21% and 16% than the corresponding cracking and failure stresses in the unreinforced walls.

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