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REINFORCING AAC MASONRY USING POLYMERIC FABRIC

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Abstract- The paper presents an experimental program intended to evaluate the characteristics of AAC masonry made with thin-joint mortar. In order to ensure the characteristics needed for its use in the Vrancea seismic zone, a program for reinforcing this type of masonry was developed. The main objective of the study presented in the paper is to reveal the contribution of the reinforcement to the ductility performance of the masonry. Results obtained for reinforced masonry are expressed with reference to those determined for ordinary masonry.

Keywords - autoclaved aerated concrete, AAC, masonry, earthquake design code

I. INTRODUCTION

Experimental programs conducted at the INCERC Bucharest Branch of the National Research and Development Institute URBAN-INCERC have revealed different types of behavior and failure mechanisms for masonry made of autoclaved aerated concrete units (AAC masonry). Different types of behavior were observed both for products of different manufacturers and for products of the same manufacturer. To determine the values of the strengths and deformation characteristics of masonry, the starting point was the idea of obtaining experimental values as close as possible to those for structural elements in masonry. For this purpose, it was proposed and accepted by masonry manufacturers to determine the characteristic values under real conditions of humidity and temperature and not in standard conditions.

Starting from the above principles, it was agreed to determine the characteristics of the component materials of masonry in parallel with those of masonry specimens. The experimental program was developed for masonry.

The steps of the experimental program were the following:

Determination of the standardized characteristics of mortar f_m, and masonry elements f_b, in ambient humidity and temperature conditions.

Determination of the characteristics of thin-joint mortar AAC masonry currently used in Romania. In this step, the mortar was placed only in horizontal joints.

Determination of the quantitative and qualitative characteristics of masonry when the mortar is used in vertical joints and the surface of the masonry unit is profiled or plane.

The last stage of the program consisted in the determination of the influence of reinforcement used in horizontal joints and in the determination of the out-of-plane (perpendicular to the wall) masonry characteristics. The reinforcement of this type of masonry, required for its use in seismic areas, was considered as an important requirement.

II. EXPERIMENTAL RESULTS

Results of tests performed in accordance with the requirements of the P100-1/2012 Romanian code (pending approval), for the studied type of masonry, are presented in the following. The main masonry characteristics, determined during the research/testing program, were:

- initial shear strength, f_{vko}, for the case of mortar being placed only in reinforced joints;
- out-of-plane bending strength perpendicular to horizontal joints, f_{xk2}, for current masonry with mortar placed only in horizontal joints, with mortar placed both in horizontal and vertical joints and with reinforcement in horizontal joints, respectively.

II.1. Description of the experimental program

Strength and deformation characteristics of structural masonry need to be determined for each type of masonry according to its specific composition (masonry unit – mortar type). It should be noted that, for each type of masonry unit, in the considered case plane units or profiled units, these specific values are essential for the designer to ensure that the structural design conforms to the national regulations, CR6 Code for masonry design and P100-1, as well as with the National Annex to Eurocode 8.

In order to perform a comparative analysis, the starting point was determining the following characteristics of masonry:

- centric compressive strength characteristics of TLMB-type AAC masonry elements, in conditions of atmospheric humidity, f_b,;
- flexural tensile strength, f_{bi}, of tongue-and-groove type AAC masonry elements;

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- compressive strength of mortar used for the specimens, f_m;

- tensile strength of polymeric fiber used for the reinforcement of horizontal joints;

- shear strength in horizontal joints, f_{vko}, for the elements made of thin-joint mortar in two variants: simple mortar and mortar reinforced with polymeric fiber;

- flexural strength perpendicular to the laying joint for masonry made of tongue-and-groove type AAC units, with the mortar laid in horizontal joint and also in vertical joint;

- flexural strength perpendicular to the laying joint, for masonry made of tongue-and-groove type AAC units with horizontal joints filled with mortar and reinforced with polymeric fabric and with vertical joints filled with mortar.

In the following, only the results obtained for strength and deformations characteristics of AAC-TLMB tongue-and-groove type masonry with thin-joint mortars in unreinforced and reinforced variants will be presented, in order to highlight the contribution of polymeric reinforcement to the failure mechanisms and to the obtained characteristic values.

II.2. Determination of the compressive strength of AAC masonry elements, f_b, under normal environmental conditions

The compressive strength was determined according SR EN 772-1 "Methods of masonry testing – Determination of the compressive strength". The tests were performed on samples of masonry units. For each masonry unit, three cubes were tested, according the specifications in Annex B of the SR EN 771-4 standard. The acclimatization was made under normal conditions of temperature and humidity.

The value of the compressive strength resulted as equal to 3.59 N/mm^2.

The variation of the compressive strength for the TLMB-type AAC masonry units tested from the samples taken from the pallets provided by the beneficiary of the testing program is presented in Figure (1).

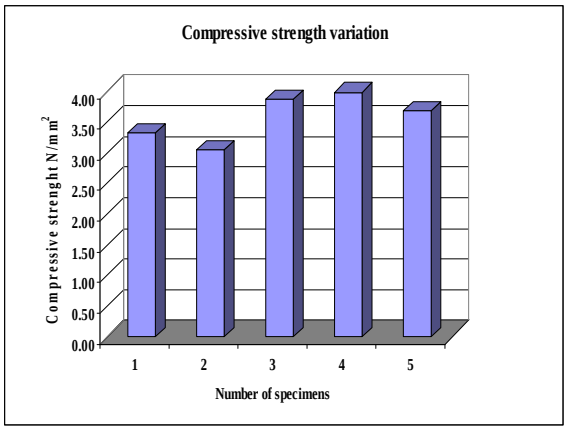


Figure 1. Compressive strength variation for AAC units

II.3. Determination of the compressive strength, f_m, of the mortar used in the masonry specimens of TLMB tongue-and-groove type AAC units

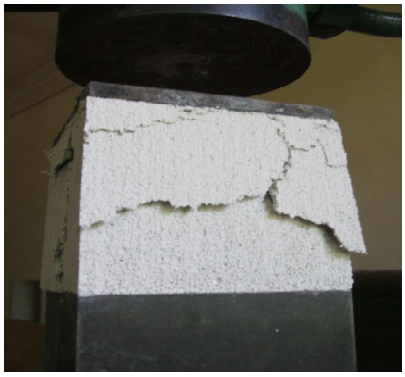
The mortar used in the specimens of TLMB tongue-and-groove type AAC units is a thin-joint mortar.

For each series of prisms, the values corresponding to the batch of mortar used for the specimens were determined.

The mean strength of thin-joint mortar for the entire experimental program was considered f_m = 26.5 N/mm^2.

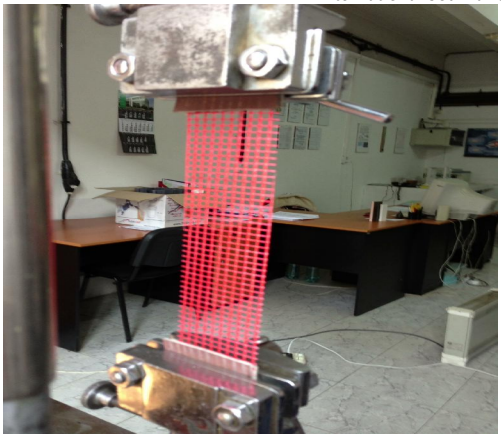
II.4. Determination of the tensile strength of polymeric fabric used as reinforcement in horizontal joints

In order to establish the tensile strength of polymeric reinforcement, tests were performed on specimens made available by the beneficiary. The specimens were 5 cm wide, being cut on the direction perpendicular to the layout of the fiber delivered as a roll. The reinforcement made of polymeric fabric has identical section and texture on both directions. The shape of the samples and the performed tests are presented in Pictures (2) and (3).



Picture 1. Cube tested at centric compression

Picture 2. Specimens after determining the tensile strength



Picture 3. Experimental layout

The results obtained from axial tension testing of the polymeric fabric are shown in Table (1).

Table 1. Tensile strength of polymeric fabric used for reinforcing the masonry specimens

Sample	Width (mm)	Vise jaws distance, A_0 (mm)	Breaking force (N)	Specimen elongation A1 (mm)	Tensile strength (N/mm)	Specific elongation (mm/mm)
1	50.04	201.05	1576	10.25	31.49	0.051
2	51.52	199.82	1568	12.31	30.43	0.062
3	48.68	200.50	1612	10.88	33.11	0.054
4	49.40	201.17	1770	10.49	35.83	0.052
5	51.19	201.10	1674	10.39	32.70	0.052
6	49.28	201.16	1472	12.22	29.87	0.061
7	50.05	201.10	1633	10.58	32.63	0.053
Mean value					**32.29**	**0.055**

The tensile strength values obtained for the polymeric fabric are used to determine its contribution to the flexure capacity, for loads applied perpendicularly to the plane of the masonry specimen.

II.5. Determination of horizontal joint shear strength, f_{vko}, for thin-joint mortar elements in two variants: simple mortar and mortar with polymeric fabric used as reinforcement

The tests for determining the initial shear strength were based on the principles from the SR EN 1052-3 standard "Testing methods for masonry – Part 3: Determination of initial shear strength". For the construction of specimens, the method of conditioning in air was used. The AAC units were kept in the laboratory, in their original package, until the construction of the specimens.

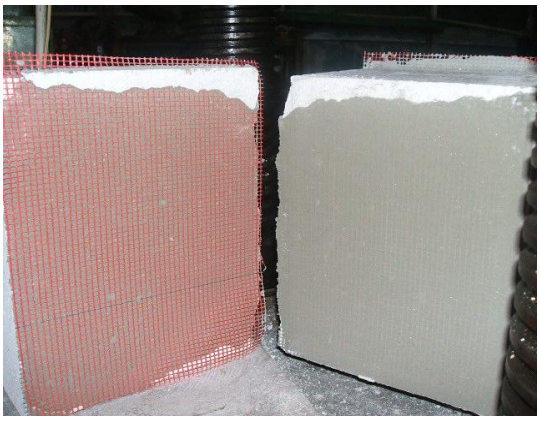
The experimental program was intended to determine the initial shear strength for masonry units and thin joint mortars with or without polymeric reinforcement.

II.5.1. Specimen testing

For determining the initial shear strength, modules made of three overlaid units were used. The test consists of breaking the specimens following a controlled section corresponding to the "A" type.

Masonry modules are supported by the bearings of the testing machine, which have the capacity to take over potential rotations without inducing concentrated stresses in the elements. The actuating plates are made of steel and they provide a good contact with masonry units. The actuating plates also have a good deformation capacity. The piston of the press being actuated by a ball-device. Actuating plates provide, as well, sufficient stiffness for applying the acting load such as to ensure an uniform distribution of the stresses.

The load was applied with a rate between 0.1 N/mm^2/minute and 0.4 N/mm^2/minute until the failure of the modules.



Picture 4. Characteristic failure of a sample tested at initial shear in horizontal joint

II.5.2. Experimental results processing

The experimental results are processed by computing the shear values for each masonry module with the following equation:

$$Fvoi = Fi,max/(2Ai) \quad [\text{N/mm2}] \qquad (1)$$

The value of initial shear strength obtained for the modules made of tongue-and-groove TLMB type AAC units unreinforced in horizontal joints was 0.491 N/mm^2.

The value of initial shear strength obtained for the modules made of tongue-and-groove TLMB type AAC units reinforced in horizontal joints was 0.344 N/mm^2.

II.6. Determination of flexural strength perpendicular to laying joint fxk2 for masonry made of tongue-and-groove type AAC units, mortar laid in horizontal joint and unfilled vertical joint

II.6.1. General

Specimens built and tested according section 8 of the SR EN 1052-2 standard were used for determining the out-of-plane flexural strength, perpendicular to the laying joint.

The testing scheme is that presented in the cited standard, the distance between the supports being chosen in order to satisfy its requirements, allowing the specimen to displace horizontally freely and without friction. Picture 5 shows the testing device.

Picture 5. Specimen for testing in flexure perpendicular to the plane of the wall and perpendicular to the laying joints

II.6.2. Testing of the specimens

The testing equipment allows loading based on the actuation scheme, providing correction of flatness variations by using platters with hemispheres located at the ends of actuation press.

The masonry modules were tested on a special stand, having a non-deformable fixed support. On this, the supporting device with the prescribed opening was fixed. It was verified that equivalent loading device provides the specified loading rate and that the actuation device is non-deformable and provides the contact with the masonry on its entire width. Where this requirement was not satisfied, rubber supports were inserted.

II.6.3. Experimental results for masonry with mortar in horizontal joints and tongue-and-groove vertical joints not filled with mortar

The results obtained by the test to out-of-plane flexure, perpendicular to the horizontal joints, were processed, for each type of masonry, according to the methodology presented in the SR EN 1052-3 standard, sections 9 and 10.

The values of out-of-plane flexural strength, perpendicular to laying joints, obtained for the modules made of tongue-and-groove TLMB-type AAC units and thin-joint mortars in horizontal joints and vertical joints not filled with mortar are given in Table (2).

Table 2. Values of flexural strength perpendicular to the plane of the wall, perpendicular to laying joints for masonry made of TLMB-type AAC units without mortar in vertical joints

Sample	**Force, F_i (N)**	**Width, b_u (mm)**	**Thickness, t_u (mm)**	**f_{xk2i} (N/mm^2)**
Sample 1	8500	800	250	0.204
Sample 2	9000	805	250	0.215
Sample 3	9500	800	250	0.228
Sample 4	9500	805	250	0.227
Sample 5	9000	800	250	0.216
Sample 6	9500	800	250	0.228
mean value				***0.220***

II.7. Determination of flexural strength perpendicular to the laying joints, f_{xk2}, for the masonry made of tongue-and-groove type AAC units, with mortar placed in horizontal and vertical joints

II.7.1. Experimental results for the masonry with mortar in horizontal joints and tongue-and-groove vertical joints filled with mortar

The results obtained during the test to out-of-plane flexure, perpendicular to horizontal joints, were processed, for each type of masonry, according to the methodology presented in the SR EN 1052-3 standard, sections 9 and 10.

The values of the out-of-plane flexural strength, perpendicular to the laying joints, obtained for the modules made of tongue-and-groove TLMB type AAC units, with thin-joint mortars in horizontal joints and vertical joints filled with mortar are given in Table (3).

Table 3. Values of flexural strength perpendicular to the plane of the wall, perpendicular to laying joint for masonry made of TLMB type AAC units with mortar in vertical joint

Sample	**Force, F_i (N)**	**Width, b_u (mm)**	**Thickness, t_u (mm)**	**f_{xk2i} (N/mm^2)**
Sample 1	12000	801	250	0.288
Sample 2	11000	801	250	0.264
Sample 3	11000	801	250	0.264
Sample 4	10500	802	250	0.251
Sample 5	13000	800	250	0.312
Sample 6	12000	801	250	0.288
mean value				***0.278***

II.8. Determination of flexural strength perpendicular to the laying joints, f_{xk2}, for masonry made of tongue-and-groove type AAC units, with mortar in horizontal joints reinforced with polymeric fabric and with vertical joints filled with mortar

II.8.1. Experimental results for masonry made of mortar in horizontal joints reinforced with polymeric fabric and tongue-and-groove vertical joints filled with mortar

The results obtained during the test to out-of-plane flexure, perpendicular to horizontal joints, were processed, for each type of masonry, according to the methodology presented in the SR EN 1052-3 standard, sections 9 and 10.

The values of out-of-plane flexural strength, perpendicular to the laying joints, obtained for the modules made of tongue-and-groove TLMB type AAC units, with thin-joint mortars in horizontal joints reinforced with polymeric fabric and vertical joints filled with mortar are given in Table (4).

Table 4. Values of flexural strength perpendicular to the plane of the wall, perpendicular to laying joints for masonry made of TLMB type AAC units with mortar in vertical joints

Sample	**Force, F_i (N)**	**Width, b_u (mm)**	**Thickness, t_u (mm)**	**f_{xk2i} (N/mm^2)**
Sample 1	12000	806	250	0.286
Sample 2	16500	806	250	0.393

Sample 3	11000	806	250	0.262
Sample 4	19000	806	250	0.453
Sample 5	10000	807	250	0.238
Sample 6	15500	807	250	0.369
mean value				***0.405***

III. CONCLUSIONS

The qualitative and quantitative analyses of the shear tests results in horizontal joints highlighted the following aspects:
- the failure occurred through mortar at the surface of separation between the reinforcement fabric and one of the layers of mortar in the joint;

- the values of initial shear strength (without compression stress), f_{vko} , have decreased with about 30 % as compared to the values obtained for a single unreinforced mortar layer; the obtained values were f_{vko}= 0.491 N/mm^2 for unreinforced joints and f_{vko} = 0.344 N/mm^2 for reinforced joints, respectively.

The analysis of the results obtained for testing to out-of-plane flexure, perpendicular to the laying joints, is summarized in Table 5.

Table 5. Analysis of out-of-plane flexural strength, perpendicular to the laying joints, for masonry made of TLMB-type AAC units

Values of out-of-plane flexural strength, perpendicular to the laying joint, for masonry made of TLMB-type AAC units	**Sample code**	f_{xk2i} **(N/mm^2)**
Mortar in horizontal joint, no mortar in vertical joint	P1	0.220
Mortar in horizontal and vertical joints	P2	0.278
Mortar in horizontal joint reinforced with polymeric fabric and mortar in vertical joint	P3	0.405

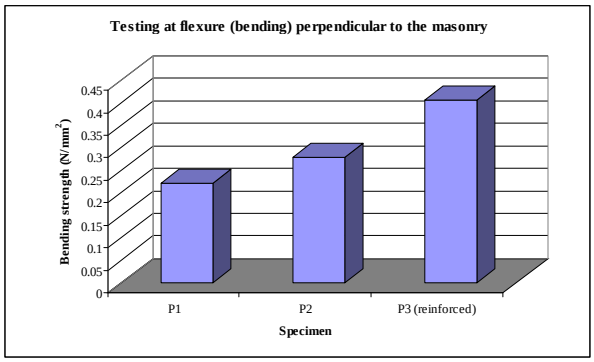


Figure 2. Strength variation for different types of masonry

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