

Radosław Jasiński and Łukasz Drobiec

Building Structures Department, Faculty of Civil Engineering, Silesian University of Technology, Gliwice 44-100, Poland

Abstract: The work presents the results of tests on the shear parameters of walls made of AAC (autoclaved aerated concrete,  $f_b = 4.0$  N/mm<sup>2</sup>) on the system mortar for thin M5 and M10 joints ( $f_m = 6.1$  N/mm<sup>2</sup> and  $f_m = 11.9$  N/mm<sup>2</sup>) and on polyurethane glue and also walls without mortar (dry masonry). The wall compression strength (on mortar M5 class) (per EN 1052-1:2000) amounted to  $f_{c,mv} = 2.97$  N/mm<sup>2</sup> ( $f_k = 2.48$  N/mm<sup>2</sup>), elastic modulus was  $E_{cm} = 2,040$  N/mm<sup>2</sup>. Various structure of bed joints and head joints were applied and the following were used as reinforcement: steel trusses of EFZ 140/Z 140 type (Z1 type) and meshes made of plastics (Z2 type). Based on the tests carried out with regard to unreinforced elements, it was shown that the filling in of head joints with mortar had an advantageous effect on the values of cracking and destruction stresses. While, with the use of reinforcement, advantageous increase of stress was obtained only when the mortar was laid twice on both bed surfaces of masonry units. The application of reinforcement in the bed joints when the mortar was laid only on one bed joints surface of the masonry units reduced the values of cracking and destruction stresses in relation to the values obtained in the unreinforced walls.

Key words: AAC, thin layer mortar joints, masonry shear strength, reinforced shear walls.

## 1. Introduction

The basic material applied in Poland for building walls is AAC (autoclaved aerated concrete) and ceramic elements. Both materials cover over 60% of the whole market of wall masonry elements. Most often, AAC is applied in residential construction, it is also widely used in industrial construction. Walls of the type of elements are also used as filling in of frame systems or they are applied in confined masonry. More and more often, metal and non-metallic reinforcement is applied in such structures due to the fact that the thickness of walls is reduced and reduces the risk of potential cracks. It is important, during to the design process, to know the basic parameters of the masonry not only made in traditional technology, but also with a different

construction of joints and reinforcement. The purpose of tests carried out was to determine the initial shear strength  $f_{vo}$ , the cracking  $\tau_{cr}$  and destruction shear stress  $\tau_u$ , strain angle  $\Theta_{cr}$  and deformation angle  $\Theta_u$ and shear modulus G as well. The indirect goal was the observation of behavior, way of cracking and damaging the test elements. To realize the planned purpose of the test, researches were divided into two series: the basic and general. A basic series was realized in accordance with EN 1052-3: 2002 [1] code while the general series conducted with according to American ASTM E519-81 code [2]. Studies in the past concerned AAC properties [3, 4] or concrete in a triaxial stress state [5], also analyzed the properties of the wall compression [6], or the effect of filling head joints on the compressive strength [7]. Occasionally, attempts were made to the impact of the vertical and horizontal reinforcement [8], and reinforcement in the walls filled frames under cyclic loads [9]. However, a comprehensive comparative

**Corresponding author:** Radosław Jasiński, Ph.D., C.Eng., research fields: masonry structures, concrete structures, FEM (finite element modeling), diagnostics of structures, and mechanics of materials.

1330

study of different types of reinforcement and the combination of different types of construction joints have not been published.

# 2. Materials

2.1 Masonry Elements, Mortar, Reinforcement and Wall

Test models used were made of blocks from AAC  $(f_b = 4.0 \text{ N/mm}^2)$  (600 × 240 × 180 mm) of one of Polish manufacturers on system mortars of M5 and M10 class ( $f_m = 6.1 \text{ N/mm}^2$  and  $f_m = 11.9 \text{ N/mm}^2$ ). Steel trusses of EFZ 140/Z 140 type (yield limit of  $f_v$  = 685 N/mm<sup>2</sup>) and meshes made of plastics (single fiber tensile strength was  $f_t = 672 \text{ N/mm}^2$ ) were used as reinforcement. In the case of trusses, reinforcement ratio was equal  $\rho_h = 0.06\%$  and was greater than the minimum level amounting  $\rho_h = 0.05\%$  recommended by EN 1996-1-1:2005+A1:2012 [10]. However, in the case of meshes made of plastics, reinforcement ratio was equal 0.01% and was lower than the minimum code level. The wall compression strength (EN 1052-1:2000 [11]) amounted to  $f_{c,mv} = 2.97 \text{ N/mm}^2 (f_k)$ = 2.48 N/mm<sup>2</sup>), elastic modulus was  $E_{cm}$  = 2,040 N/mm<sup>2</sup>.

# 3. Test Models and Test Program

### 3.1 Test Stands and Test Program for the Basic Series

The tested models were composed of two wall elements joined with mineral mortar or polyurethane glue. When using the mineral mortar, models with the width equal to the wall thickness or two strips with the width of 50 mm each were made. The thickness of the mortar layer after laying in joints was each time equal to 3~4 mm. When the elements were joined with the use of polyurethane glue on the support surfaces, two stripes of glue were placed. A view of models while doing masonry work is presented in Fig. 1. Models, after construction, were stored in the laboratory conditions at the temperature of +20 °C and air relative humidity of 70%~85%. Pursuant to the requirements of EN 1052-3:2004 [1] standard in terms of each type of mortar, nine elements were made. The test elements were marked with a capital letter S and additional capital letters M, MP and P which stood for the type of mortar applied. Apart from models joined with various types of mortar, additional S series was made in which no mortar was used (dry wall). The program of tests on initial shear strength of the wall is shown in Table 1.



Fig. 1 The performance of the elements of basic series: (a) models with thin bed joint; (b) models with the band joint; (c) models with the joint made of polyurethane glue.

Series name	Number of elements	Type of joint
M5 SM	9	M5 mortar for thin-layer joints. Thin joint with the width equal to the wall width ( $t=180$ mm).
M5 SMP	9	M5 mortar for thin-layer joints (shell bedded masonry). Two strips with the width of 50 mm each.
SP SP	9	System polyurethane glue
"dry masonry" S	9	No mortar (dry masonry)
Total	36	

Table 1 The program of tests—basic series.

Because of the dimensions of the wall elements pursuant to EN 1052-3:2004 [1] in the tests on initial compression strength, test elements of B type were used. The samples are composed of two wall elements properly cut. The dimensions and shape of test elements are shown in Fig. 2.

## 3.2 Test Models and Test Program for the Basic Series

All models made were characterized with the same dimensions and shapes. The length of the model was l = 1,180 mm, the height was h = 1,212 mm, and the thickness corresponded to the thickness of a single masonry units t = 180 mm (Fig. 3).

Eleven series of test models were performed in terms of which from 3 to 6 test elements were examined. The given series were differentiated in terms of type of mortar, filling in of head joints or reinforcement applied. In the series marked as RL-S-N, 6 elements without reinforcement and filling in of head joints were made.

While in RL-S-NW series composed also of 6 elements, the head joints were filled. When reinforcement in the form of trusses was applied a series marked as RL-S-Z1 composed of 3 models and also 3 element series of RL-S-Z1W with filled in head joints were made. A series of elements reinforced with trusses were supplemented additionally with 3 elements in which double mortar laying on blocks was applied. In cases in which mesh made of plastics was applied, the procedure was similar while examining 2 three-element series marked as RL-S-Z2 and RL-S-Z2W with filled head joints. For the purposes of making elements, system mortar of M5 class was applied. While in two additional series marked as RL-S-N10 and RL-S-Z1-N10 systems, mortar of M10 class was applied. In RL-S-N10 series, a thin layer joint with the width equal to the wall thickness was made while in RL-S-Z1-N10 series with double mortar laying reinforcement in the form of trusses was applied. Additionally, a series of RL-S-NS elements was



Fig. 2 Geometry and dimensions of test models of the basic series.



Fig. 3 Geometry, dimensions, location and details of reinforcement of test models of the basic series (1—steel flat bar 1.5 × 8 mm, 2—round bar 1.5 mm, 3—mesh plot fiber, 4—mesh matrix fiber).

made in which two band joints were applied with the width of 50 mm and RL-S-NP series in which polyurethane glue was used instead of mineral mortar. A test program general series is included in Table 2.

# 3.3 Test Stands and Testing Technique for the Basic Series

Tests were carried out in a specially constructed setup (Fig. 4) which allowed for the realization of vertical load (shearing) and compression load perpendicular to the bed joints. The stand was composed of a steel frame (4) (C profil 80), in which test element I was placed. The steel frame of the stand was used for inducing horizontal compression stresses perpendicular to the bed joints. The compression load was induced with the use of a hydraulic jack (3), while the compression force was measured with the

use of a force gauge (2) with the range of 100 kN. The compression force was transmitted on the test element in the center of its weight through steel sheet metals and Teflon washer (7). The frame with the test element was placed in the universal testing machine with the range of 3,000 kN, which was used for inducing shearing load (5) with the speed of 0.3 N/mm<sup>2</sup>/s. The measurement of vertical shearing force was made with the use of an force gauge (8) with the range of 100 kN. The test specimens were placed on the bottom plate of the universal testing machine (6) each time on the steel cylinders with the diameter of 12 mm and steel sheet metals. The shearing load was induced on the wall element from the header of the press by two sheet metals separated with steel cylinders. As compression strength of wall elements  $f_b < 10 \text{ N/mm}^2$ , the tests on initial shear strength were

Series name	Mortar class	Type of ioint	Type of reinforcement	Number of elements
M5 RL-S-N	M5	Thin-layer joint with the width equal to the wall width	Without reinforcement	6
M5 M5	M5	Thin-layer joint with the width equal to the wall width, filled in head joints	Without reinforcement	6
RL-S-Z1	M5	Thin-layer joint with the width equal to the wall width.	Reinforcement of truss type	3
RL-S-ZIW	M5	Thin-layer joint with the width equal to the wall width, filled in head joints	Reinforcement of truss type	3
M5 RL-S-Z2	M5	Thin-layer joint with the width equal to the wall width	Reinforcement of mesh made of plastics type	3
M5 M5 RL-S-Z2W	M5	Thin-layer joint with the width equal to the wall width, filled in head joints	Reinforcement of mesh made of plastics type	3
N3 RL-S-Z1-4-6	M5	Thin-layer joint with the width equal to the wall width. Double mortar laying	Reinforcement of truss type	3
M10 RL-S-N10	M10	Thin-layer joint with the width equal to the wall width	Without reinforcement	6
M10 RL-S-Z1-N10	M10	Thin-layer joint with the width equal to the wall width	Reinforcement of truss type	3

Table 2
 The program of tests—general series.

Comparison Research of Bed Joints Construction and Bed Joints Reinforcement on Shear Parameters of AAC Masonry Walls



Fig. 4 The test stand used in the tests of the basic series (description in the text).

carried out at three various values of normal stresses perpendicular to the plane of bed joints which amounted to:  $f_{p,i} = 0.1$ , 0.3 and 0.5 N/mm<sup>2</sup>, calculated from

$$f_{p,i} = \frac{F_{p,i}}{A_h} \tag{1}$$

where,  $F_{p,i}$ —value of initial compression load;  $A_h$ —cross section area of test element (the units bed area).

Apart from the automatic measurement of vertical and horizontal forces, the measurement of mutual dislocations of wall elements joined with mortar with the use of fixed from both sides displacement gauges (9) was carried out. The measurement was performed at the mid-length of the bed joint.

The highest load registered by the universal testing machine at which the displacement of the machine piston increased suddenly were treated as the breaking force  $F_{i,max}$  at which for the given test element compression strength  $f_{voi}$  was calculated as the quotient of load  $F_{i,max}$  and area of bed surface  $A_h$  from:

$$f_{voi} = \frac{F_{i,\max}}{2A_h} \tag{2}$$

where,  $F_{i,\max}$ —value of maximum shearing force obtained for the nth test element.

Initial shear strengths  $f_{voi}$  calculated for each test element were plotted on the diagram in the function of initial compression stresses  $f_{pi}$  (Fig. 5). In the results obtained, a straight was plotted with the method of the



Fig. 5 The principle for determining basic shearing parameters acc. EN 1052-3:2004 (1—regression straight, 2—corrected regression straight).

least squares. From the straight equation, the values of initial shear strength on the wall  $f_{vo}$  were read with the accuracy of 0.01 N/mm<sup>2</sup> in the place in which it intersected with the vertical axis of the system and the internal friction angle  $\alpha$  with the accuracy to one degree.

# 3.4 Test Stand and Testing Technique for the General Series

Test elements *I* were placed in special steel sockets (2), so that one of the diagonals was set vertically and the arms of the steel fixing covered ca. 1/10 of the length (height) of the tested element. The sockets were equipped in cylindrical wrist joint which eliminated the influence of eccentricities which were formed by accident while loading. The test models equipped in steel fixing were placed on a cart (7) under the steel frame (6) and loaded by means of applying constant increment of the hydraulic jack piston (3), until the moment the element was damaged. The view of the test setup used for testing wall strength in the presence of oblique shearing is presented in Fig. 6.

During the rests, the loading force was measured with the use of two combined force gauges (4) with the range of 100 kN each and horizontal and vertical displacements were also measured with the use of gauges (5). The displacement sensors were placed along two diagonals on both sides of the model, the measurement was performed on the base length amounting to 932 mm. The length of the base was selected pursuant to the guidelines of ASTM E519-81 standard so that they covered the greatest length of the diagonal.

At each registered force  $F_i$  (at the *n*th level of load), the value of average contact stresses  $\tau_{v,i}$  was calculated as the quotient of load  $F_i$  and area of the wall cross section (along the diagonal)  $A_h$  from:

$$\tau_{v,i} = \frac{F_i}{A_h} = \frac{F_i}{t\sqrt{l^2 + h^2}}$$
(3)

where,  $F_i$  = vertical force at the nth level of load; t = 180 mm wall thickness; l = 1,180 mm wall length, h = 1,212 mm wall height.

The strain angle  $\Theta_i$  and shear modulus  $G_i$  was determined in the function of load  $F_i$  from

$$\Theta = 2 \operatorname{arctg}\left(\frac{x - y + |\Delta x| + |\Delta y|}{x + y + |\Delta x| - |\Delta y|}\right) \to G = \frac{\tau}{\Theta} \quad (4)$$

where, x, y—length of the model diagonals in the perpendicular and parallel direction to the force,  $\Theta$ —strain angle;  $\Delta x$ ,  $\Delta y$ —increment of the model diagonal lengths; G—shear modulus.



Fig. 6 The test setup used in the general series (description in the text).

The values of cracking stresses and  $\tau_{cr}$ corresponding to them angles  $\Theta_{cr}$  and shear modulus  $G_{cr}$  were determined for the cracking forces  $F_{cr}$ , at which the appearance of new cracks with the width of 0.1 mm was observed. While the destruction stresses  $\tau_u$  and strain angles  $\Theta_u$  were determined at the forces which caused model damage (the further increase of loads with the increase of wall strain angle was not registered).

## 4. Test Results

#### 4.1 Test Results of the Tests of the Basic Series

Table 3 shows the results of the tests on strength parameters for all examined element series. In the basic case when thin layer joint was applied with the width (SM series models) equal to the wall thickness, the value of initial shear strength amounted to  $f_{vo}$  = N/mm<sup>2</sup>, and the characteristic strength 0.31 determined based on the above was  $f_{vok} = 0.24 \text{ N/mm}^2$ . The value of the internal friction angle was  $\alpha = 32^{\circ}$ . The calculated characteristic tangent of the initial friction angle was  $0.8 \text{tg}\alpha = 0.50$ .

When thin layer hand joint was applied with the

Series	$f_{vo}$ (N/mm <sup>2</sup> )	$f_{vko} (\mathrm{N/mm}^2)$	α (°)	$0.8$ tg $\alpha$	
M5	0.31	0.24	32	0.50	
M5	0.13	0.11	34	0.54	
	0.28	0.22	28	0.43	
"dry masonry"	0	0	43	0.74	

equal to  $2 \times 50$  mm, the value of initial shear strength amounted to  $f_{vo} = 0.13$  N/mm<sup>2</sup>, and the characteristic strength determined based on the above was  $f_{vok} =$ 0.11 N/mm<sup>2</sup>. The value of the internal friction angle was  $\alpha = 34^\circ$ . The calculated characteristic tangent of the initial friction angle was  $0.8 \text{tg}\alpha = 54$ . In cases when polyurethane glue was used for joining the wall elements (SP series models), the value of initial shear strength amounted to  $f_{vo} = 0.28 \text{ N/mm}^2$ , and the characteristic strength determined based on the above was  $f_{vko} = 0.22$  N/mm<sup>2</sup>. The value of the internal friction angle was  $\alpha = 28^{\circ}$ . The calculated characteristic tangent of the initial friction angle was 0.8 tg $\alpha$  = 0.43. In the models of S series in which no durable connection between the masonry units (S models series-dry masonry), the value of internal friction angle was  $\alpha = 43^{\circ}$ , and the characteristic value was  $\alpha_k = 36^\circ$ . The calculated characteristic tangent of the initial friction angle was  $0.8 \text{tg}\alpha = 0.74$ . Comparison of the obtained test results and determined characteristic values with the parameters recommended by PN-EN 1996-1-1 2013 [12]standard

width (SMP series models-shell bedded masonry)

is shown in Table 4. Fig. 7 shows the comparison of test results and a straight drawn based on dependence which determined the shear strength per PN-EN 1996-1-1:2013.

The initial shearing strength obtained in the tests was in all series of elements smaller than the Polish code value. In case of joint with the width equal to the wall thickness, the difference was only 4% while in case of joints on polyurethane glue, it was over 12%.

The highest difference of 66% was in case of elements joined with a band joint. In EN 1996-1-1:2005 + A1: 2012 code, value  $f_{vko}$  is equal to 0.30 N/mm<sup>2</sup> and thus values obtained in the studies were distinctly smaller. The reverse tendency was stated in case of the internal friction angle of the mortar in the joint  $0.8 \text{tg}\alpha$ . The values obtained in the tests were each time higher than those recommended in the standard  $0.8 \text{tg}\alpha = 0.4$ . The maximum increase of the internal friction angle

 Table 4
 Comparison of the tests results on the basic series.





Fig. 7 Comparison of test results with the dependence proposed in PN-EN 1996-1-1:2013 [12].

amounting to 85% was obtained in case of elements in which no mortar was applied, in case of joints made of mortar with the width equal to the wall thickness, it was 25%. Models with the joint made of polyurethane glue characterized with the smallest friction coefficient value which, however was 8% higher than the standard value.

## 4.2 Test Results of the Tests of the General Series

The damage of all the reinforced and unreinforced test elements in which single laid mortar was applied in bed joints was of sudden character, it means that while loading no cracks visible on the wall surface appeared, only single and not very intensive crackles were heard. The damage of the specimens with bed joints width equal to the wall width, shell bedded masonry and masonry on system polyurethane glue were similar. The destruction of the elements was based on the loss of adhesion between the masonry units and mortar in the bed joints and cracking in the central area of the wall. (Fig. 8a). In the elements in which head joints were filled in, cracks in the wall region were also observed (Fig. 8b). The elements with the reinforcement (trusses and meshes) in which the mortar applying only on single bed surface of masonry units behaved just like unreinforced specimens with unfilled head joints. The loss of adhesion occurred at the interface of the reinforcement



Fig. 8 Characteristics cracking patterns of unreinforced and reinforced specimens: (a) elements on mineral mortar without the filled in head joints; (b) elements on mineral mortar with the filled in head joints; (c) elements reinforced with trusses with the mortar laid on one side; (d) elements reinforced with meshes made of plastics with the mortar laid on one side.

and masonry units (Figs. 8c and 8d).

In the reinforced models in which mortar was laid on the bed joint and on the support surfaces of the masonry units (double mortar laying), the character of damage changed. First cracks of the wall elements in the central wall area were formed and then with the load increase, the secondary loss of adhesion between the wall elements and mortar took place (Fig. 9).

In all the elements on M5 and M10 mineral mortars until the time of cracking, the strain angles changed proportionally to stresses. Generally after cracking, the element was damaged without the increase of strain angles. The exception were the elements of RL-S-Z1-4, RL-S-Z1-5, RL-S-Z1-6 series in which the reinforcement was laid in double mortar laying was applied. After cracking the increase of strain angles took place and then reinforcement and damage. Table 5 shows the average results of stresses in the moment of cracking  $\tau_{cr,mv}$  and destruction  $\tau_{u,mv}$ , strain angles in the time of cracking  $\Theta_{cr,mv}$  and destruction  $\Theta_{u,mv}$  and shear modulus  $G_{cr,mv}$  as well. In the models with thin bed joint from M5 mortar with the thickness equal to the wall width, in the time of cracking, average stresses amounted to  $\tau_{cr,mv} = 0.192 \text{ N/mm}^2$ while in other unreinforced and reinforced (single mortar laying) series, the stresses were smaller. The exceptions were models in which head joints were filled in, both with and without the reinforcement. Greater stresses in the time of cracking  $\tau_{cr,mv} = 0.214$ N/mm<sup>2</sup> were present in the model reinforced with trusses in which mortar was laid in double layers. When mortar of M10 class was used, the contact stresses in the moment of cracking amounted to  $\tau_{cr,mv}$ =  $0.180 \text{ N/mm}^2$ , that is less than in models on M5 class mortar. The maximum average stress at the time of destruction obtained in the models with thin bed joint from M5 mortar with the thickness of the wall width amounted to  $\tau_{u,mv} = 0.196 \text{ N/mm}^2$ . In other series of elements made on the same mortar, smaller stresses were obtained. The exceptions were the unreinforced and reinforced elements in which the head joints were filled with mortar. In the model reinforced with trusses with mortar laid in double layers, essentially higher stress values were obtained and they amounted to  $\tau_{u,mv} = 0.269 \text{ N/mm}^2$ . When mortar of M10 class was used, the contact stresses in the moment of breaking amounted to  $\tau_{cr,mv} = 0.189 \text{ N/mm}^2$ , that is slightly less than in analogical models on M5 class mortar.

In the models with thin bed joint from M5 mortar with the thickness equal to the wall width, cracks were present at the average strain angle of  $\tau_{cr,mv} = 0.587$ mrad in other series, the strain angles in the moment of cracking were smaller. Exceptions were unreinforced models that were made for polyurethane glue where the average strain angle amounted  $\tau_{cr,mv} =$ 1.159 mrad. Models with reinforcement in the form of trusses and meshes made of plastics showed smaller strain angles. Only when mortar was laid in double layers greater strain angles  $\tau_{cr,mv} = 0.668$  mrad was obtained. When mortar of M10 class was used, the strain angles of  $\tau_{cr,mv} = 0.518$  mrad was obtained so similar to models on M5 class mortar.



Fig. 9 Example of cracking patterns of specimens reinforced with truss reinforcement with the double mortar laying.

Series	$\tau_{cr,mv}$ (N/mm <sup>2</sup> )	$\tau_{u,mv}$ (N/mm <sup>2</sup> )	$\Theta_{cr,mv}$ (N/mm <sup>2</sup> )	$G_{cr,mv}$ (N/mm <sup>2</sup> )	$\Theta_{u,mv}$ (mrad)
M5	0.192	0.196	0.587	329	0.601
MS M5	0.282	0.292	0.500	561	0.549
RL-S-ZI	0.141	0.157	0.426	331	0.530
RL-S-ZIW	0.241	0.242	0.393	607	0.410
N5 DI S 72	0.126	0.130	0.417	303	0.458
RL-S-Z2	0.182	0.186	0.504	408	0.574
RL-S-ZL2W N5 RL-S-ZL4-6	0.241	0.269	0.668	361	3.767
M10	0.180	0.189	0.518	363	0.653
RL-S-N10	0.240	0.285	0.713	337	3.282
KL-5-21-110	0.135	0.138	1.159	119	1.237
RL-S-NP M5 RL-S-NS	0.123	0.126	0.379	325	0.401

Table 5The results of tests on the general series.

1340

Comparison Research of Bed Joints Construction and Bed Joints Reinforcement on Shear Parameters of AAC Masonry Walls



Fig. 10 The results of tests of the general series: (a) values of cracking stresses  $\tau_{cr,mv}$  and breaking stresses  $\tau_{u,mv}$ ; (b) values of shape distortion angles in the moment of cracking  $\Theta_{cr,mv}$  and breaking  $\Theta_{u,mv}$ ; (c) values of shape distortion modules  $G_{cr,mv}$ .

Distinctly differentiated deformability of the walls meant that the shear modules shear  $G_{cr,mv}$  was clearly different. The walls of the in thin mortar joints M5 had a module equal to  $G_{cr,mv} = 329 \text{ N/mm}^2$ . Only if the walls of the polyurethane glue were obtained less than 60% modulus value, in all other series modulus are comparable or greater. At the time of the destruction of the greatest deformation angle characterized by elements which were applicable truss reinforcement in double mortar laying of obtaining  $\Theta_{u,mv} = 3.767$  mrad. A little smaller results were obtained using mortar class M10 ( $\Theta_{u,mv}$  = 3.282 mrad). Fig. 10a shows a collective comparison of test results in the form of stress values in the moment of cracking and breaking while Fig. 10b shows collective values of strain angles in the moment of cracking and breaking. Fig. 10c presents the values of shear modulus of all tested models.

The tests showed that regardless of the class applied and way of laying mortar, the cracking and damage process was of sudden character related to the loss of adhesion between the wall elements and mortar. The exceptions were the elements reinforced with trusses in which mortar laid in bed joints and on the face surfaces of masonry units was applied. Then first cracks of wall elements appeared and then cracks of bed joints and head joints. The application of reinforcement in the bed joints when the mortar was laid only on one bed surface of the wall elements reduces the values of cracking and breaking stresses in relation to the values obtained in the unreinforced walls. The increase of the values of cracking and destruction stresses as well as shear modulus in the reinforced walls was present only when filled in head

joints were applied. The most advantageous type of reinforcement was trusses in case of which ca. 50% increase of cracking and breaking stresses was obtained. The advantageous impact of reinforcement on strength parameters was achieved only when the mortar was laid twice on both support surfaces of wall elements.

## 5. Summary

1342

Based on the tests of the basic series carried out, it was stated that:

• initial shear strength masonry made on mineral mortar were within the range of  $f_{vo} = 0.13 \div 31 \text{ N/mm}^2$ , and characteristic strengths determined based on the above were within the range  $f_{vko} = 0.11 \div 0.24 \text{ N/mm}^2$ ;

• when polyurethane glue was applied the initial shear strength was  $f_{vo} = 0.28 \text{ N/mm}^2$ , and corresponding to it characteristic strength was  $f_{vko} = 0.22 \text{ N/mm}^2$ ,

• in the elements joined with the use of mineral mortar the internal friction angle tangent values obtained were within the range of  $0.8 \text{tg}\alpha = 0.50 \div 0.54$ , and when polyurethane glue was used it was  $0.8 \text{tg}\alpha = 0.43$ ;

When considering the test results obtained in comparison to entries of Eurocode (Polish National Annex), the following was achieved:

• the characteristic initial shear strength of walls in which mortar with the width equal to the wall thickness was applied was slightly smaller than the standard value amounting to 0.25 N/mm<sup>2</sup>;

• when band joints were used, the characteristic initial shear strength amounted to  $0.11 \text{ N/mm}^2$ , and it was over 54% smaller than the standard value;

• in the models in which elements were joined with polyurethane glue, the characteristic initial shear strength was 12% smaller than the standard value applied with regard to walls on mineral mortar;

• in relation to the internal friction angle of the mortar in the joint  $0.8 \text{tg}\alpha$ , the values achieved in the tests were greater than recommended in the standard  $0.8 \text{tg}\alpha = 0.4$ . The maximum increase of the internal

friction angle was achieved in case of elements without mortar and the smallest in the elements with band joints.

One can also draw general conclusions based on the general series tests carried out:

• the performance of head joints in with mortar has a beneficial effect on the values of cracking and destruction stresses. It also limits the shape distortions while cracking;

• application of reinforcement in the bed joints when mortar is laid only on one support surface of wall elements has a disadvantageous effect on the values of cracking and destruction stresses;

• the advantageous impact of reinforcement on strength parameters was achieved only when the mortar was laid on both bed surfaces of masonry units;

• the application of mortar of double strength did not cause the proportional increase of the values of cracking and breaking stresses with regard to the elements made on the mortar of lower class.

## Acknowledgments

The authors of researches express special gratitude to SOLBET Company for essential and material assistance in the course of tests realization.

## References

- [1] CEN. 2004. EN 1052-3:2004 Methods Of Test For Masonry—Part 3: Determination Of Initial Shear Strength.
- [2] ASTM. 1981. ASTM E519-81 Standard Test Method for Diagonal Tension (Shear) of Masonry Assemblages.
- [3] Blaschke, R. 1990. "Zum Tragverhalten voh Porenbetoh-Plansteihmauerwerk Bearing Behaviour of AAC-Precision-Block Masonry." In Proceedings of 9th International Brick and Block Masonry Conference Berlin, Germany, 132-40.
- [4] Vratsanou, V., and Langer, P. 2000. "Experimental Study on the Shear Resistance of AAC Masonry Walls." In Proceedings of the 12th International Brick and Block Masonry Conference. Madrid, 1907-15.
- [5] Dias, M. J. L. 2005. "Susceptibility for Cracking of Masonry Mortar Joints When Subjected to Compression." In *Proceedings of the 10th Canadian Masonry Symposium*. (CD-ROM)

- [6] Piekarczyk, A., and Drobiec, Ł., and Kubica, J. 2000. "AAC Blocks Masonry Compressed Perpendicular and Parallel to the Bed Joints." In Proceedings of the 12th International Brick and Block Masonry Conference, 1447-54.
- [7] Kubica, J. 2008. "Unreinforced AAC Block's Masonry under Axially Compression—An Influence of Not Filed Head Joints." In *Proceedings of 8th International Masonry Conference 2010 in Dresden*, 333-40.
- [8] Mandirola, M., Penna, A., Rota, M., and Magenes, G. 2012. "Experimental Assessment of the Shear Response of Autoclaved Aerated Concrete (AAC) Masonry with Flat Truss Bed-Joint Reinforcement." In Proceedings of 15th International Brick and Block Masonry Conference Florianópolis. (CD-ROM)
- [9] Penna, A., Magenes, G. G., Calvi, G. M., and Costa, A. A. 2008. "Seismic Performance of AAC Infill and Bearing Walls with Different Reinforcement Solutions." In Proceedings of the 14th International Brick and Block Masonry Conference Sydney, Australia. (CD-ROM)
- [10] CEN. 2012. EN 1996-1-1:2005+A1:2012 Eurocode 6. Design of Masonry Structures. Part 1-1: Common Rules for Reinforced and Unreinforced Masonry Structures.
- [11] CEN. 2000. EN 1052-1:2000 Methods Of Test For Masonry—Part 1: Determination Of Compression Strength.
- PKN. 2013. PN-EN 1996-1-1:2005+A1:2013-05
   Eurocode 6. Design of Masonry Structures. Part 1-1: Common Rules for Reinforced and Unreinforced Masonry Structures. (in Polish)