The effect of polyurethane foam glue on the strength and deformability of aerated concrete masonry when using it as a masonry mortar

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Abstract. The article presents the results of experimental studies of masonry made of cellular concrete blocks of autoclave hardening YTONG produced by JSC «Kcell-Aeroblock-Center» on the adhesive composition (polyurethane glue) Dryfix (POLYPAG AG). The tests included comprehensive studies of the strength and deformability of masonry walls made of cellular concrete blocks, under various types of stress state of structures: central and off-center compression of masonry walls, axial tension on bandaged and unbound seams, tensile bending on bandaged and unbound seams, shear with an assessment of tangential adhesion. Tests have confirmed the inconsistency of the technology of laying blocks of cellular concrete on the adhesive composition of Dryfix with incomplete filling of seams. This technology has a significant impact on the strength of the masonry during bending: the adhesion of the blocks to each other with such an adhesive composition applied to the surface of the block is significantly lower than the value obtained when testing the blocks for axial tension. According to the results of the experiments, the value of the temporary resistance to axial stretching along the unbound section (normal adhesion) of the masonry, the values of the calculated resistance of the masonry to stretching during bending along the unbound and tied sections, as well as the value of the calculated resistance of the masonry under central compression were determined.

1 Introduction

The problem of ensuring a comfortable level of work and living of a person in industrial and residential premises of buildings is associated with a significant expenditure of energy resources, the volume of consumption of which is not directly dependent on their extraction and reproduction.

According to the EU, if appropriate measures are not taken, Europe's dependence on external energy supplies, and Russia's dependence on energy production, will increase by 65÷70% by 2030 compared to the beginning of the XXI century. In this regard, for the possibility of reducing energy costs, the EU adopted the document «EU-Klimatschutzpaket...
20-20-20», which set the goal of reducing energy consumption by 20% compared to 1990. According to Russian and European sources, 40% of the total primary energy consumption is used for building maintenance, of which 75-80% is used for heating in winter and cooling in summer of residential and administrative buildings.

To improve the energy efficiency of buildings in Europe, a document was developed – the European Directive on ensuring the energy efficiency of buildings «ERBD» (Energy Performance of Buildings Directive). In the period from 06.07.2010 to 31.12.2020, the EU member states must ensure that all new buildings under construction must generate as much energy as they consume, i.e. the goal of this step is to develop houses with zero energy consumption. The Russian construction industry faces a similar task.

One of the main ways to reduce heat loss through enclosing structures is the use of modern wall materials made of cellular concrete and thaumalite with reduced thermal conductivity characteristics. Thus, according to the company "YTONG" for the period from 1950 to 2015, due to the improvement of the production technology of cellular concrete blocks and, directly, the components of the block material itself (concrete), the thermal conductivity coefficient of autoclaved aerated concrete blocks decreased from 0,21 W / m×°C to 0,07 W/m×°C. At the same time, the average annual growth of the cellular concrete market share in Russia for the period from 2005 to 2020 amounted to 22÷25%.

This is due both to an increase in the production of cellular concrete blocks (according to the National Association of Autoclaved Aerated Concrete Manufacturers, Russia has purchased more than 500 plants with high-tech equipment for the production of cellular concrete blocks in Europe), and to the growth of the low-rise construction segment and the lower price of aerated concrete compared to the price of brick products. In addition, as shown by experimental studies performed at the NIIZHB (Research Institute of Reinforced Concrete), the use of modern technology for the production of cellular concrete blocks allowed to reduce the coefficient of variation in the strength of the products from 18% to 5÷7%. This is a very high indicator, and it indicates a very low spread of the strength of cellular concrete and, as a result, high reliability of the products. For comparison: according to SP 15.13330.2020, it is allowed to produce building blocks made of cellular concrete with a coefficient of variation of compressive strength of 15÷17%. This is evidence that the regulatory documents on stone structures in force on the territory of the Russian Federation lag behind the requirements of the time and do not correspond to the level of production technology of modern cellular concrete structures.

A lot of domestic [1-10] and foreign scientists [11-13], including the authors of this article [14,15], have been engaged in studies on the strength characteristics of masonry made of cellular concrete and gas silicate blocks on various adhesive compositions.

### 2 Research methods and results

In the Laboratory of the Department «Reinforced Concrete and Stone Structures» (Head of the Department prof. A. G. Tamrazyan) of the Moscow State University of Civil Engineering, comprehensive studies of the strength and deformability of masonry walls made of cellular concrete blocks produced by «Bonolit» and JSC «Kcell-Aeroblock-Center» were carried out under various types of stressed state of structures:
- central and off-center compression of masonry walls;
- axial tension along the bandaged and non-bandaged seams;
- for stretching when bending along the bandaged and non-bandaged seams;
- for a shift with an estimate of tangential coupling.

The results of the compression testing of cubes and prisms, as well as two samples for axial tension (figure 1a) showed the following (table 1).
• Analysis of the results of compression tests allows us to note that when the concrete compressive strength class B3.5 was established according to factory tests, the cube samples showed a concrete class equal to B3.9 by interpolation. At the same time, according to the NIIZHB (Research Institute of Reinforced Concrete), the coefficient of variation for cellular concrete manufactured at the plant of JSC «Kcell-Aeroblock-Center» was assumed to be equal to v=6%.

• The value of the temporary resistance to axial stretching along an unbound seam (normal adhesion) of the masonry of prototypes made of autoclave-hardened cellular concrete blocks made on an adhesive composition varied in the range from 0,23 to 0,32 MPa (on average 0,28 MPa). According to p.p. 6.14.4, 6.14.5 SP 14.13330.2018 for masonry of the I-th category of walls of buildings erected in earthquake-prone areas of the Russian Federation, the temporary resistance to axial tension should be at least $R_{ut} \geq 0,18$ MPa. The values of the normal adhesion of the masonry walls on the Dryfix adhesive solution obtained from the experiment are 55% higher than the values of the standard temporary resistance to axial tension along an unbound seam for the masonry walls of the I-th category. The specified parameter of the masonry has a significant impact on its strength under the action of loads (wind and seismic effects) that cause the walls to bend from their plane.

• As can be seen from the photo in figure 1b, the destruction of most of the two samples under axial tension occurred along the concrete body, so when using the Dryfix adhesive composition to connect cellular concrete blocks, the strength under axial tension of the masonry along the seam is higher than the tensile strength of cellular concrete. The rupture occurred according to the material of the masonry. In the case of using cement mortar to connect the blocks, the destruction occurred along the seam.

![Sample "two": in the process of testing for normal adhesion (a); the nature of destruction (b)](image)

**Table 1. Results of testing of prototypes for normal adhesion**

<table>
<thead>
<tr>
<th>№</th>
<th>Sample dimensions (mm)</th>
<th>N (N)</th>
<th>$R_{ut}$ (MPa)</th>
<th>$\frac{R_{ult(m)}}{R_{uc}}$ (MPa)</th>
<th>Relative strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>122×152</td>
<td>4250</td>
<td>0,23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>125×151</td>
<td>5650</td>
<td>0,3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>120×150</td>
<td>5750</td>
<td>0,32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>124×150</td>
<td>6000</td>
<td>0,32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>122×150</td>
<td>5150</td>
<td>0,28</td>
<td>0,28/0,18</td>
<td>155%/100%</td>
</tr>
<tr>
<td>6</td>
<td>119×152</td>
<td>4600</td>
<td>0,25</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
To assess the strength of the masonry walls during bending, a special power frame was made (see figure 2). Loading schemes of prototypes with a size of 1000×900×200 mm during tests on bandaged and unbound sections are shown in figure 3.

Fig. 2. General view of the power frame for bending tests of samples

(a)  (b)

Fig. 3. Scheme of testing of prototypes for bending on an unbound (a) and on a tied cross-section (b)

The analysis of the test results of experimental samples of masonry made of cellular concrete blocks for stretching when bending along unbound and bandaged seams allowed us to establish the following.

- For masonry walls of buildings designed in accordance with the requirements of SP 15.13330.2020, the calculated tensile strength of masonry over an unbound cross-section should be taken 0.18 MPa instead of the value of 0.12 MPa indicated in table.11. For masonry walls of buildings designed in earthquake-prone regions, in accordance with the requirements of SP 14.13330.2018, the value of $R_{tb1}$ should be taken equal to: $R_{tb1} = 0.8 \times R_u = 0.8 \times 0.28 = 0.224$ MPa.

- The results of tests of experimental images for stretching when bending along a bandaged cross-section and the nature of the destruction of the samples showed that the technology of laying blocks of cellular concrete on the Dryfix adhesive composition with incomplete filling of the seams has a significant impact on the strength of the masonry during bending: the adhesion of the blocks to each other when applying the adhesive composition to the block surface is significantly lower than the value obtained when testing the blocks for axial tension.
In accordance with the work program, 3 samples with dimensions of 1180×1000(H)×200 mm and 3 samples with dimensions of 1180×1000(H)×100 mm were made of YTONG autoclave-hardened cellular concrete blocks on the Dryfix adhesive composition under central compression to determine the design resistance of masonry walls.

The objectives of the experimental studies included:
- study of the features of the work of walls made of cellular concrete blocks mounted on the adhesive composition of Dryfix, with central and off-center compression;
- determination of the calculated compression resistance of masonry walls made of cellular concrete blocks on the adhesive composition of Dryfix.

The prototypes were made of cellular concrete blocks of autoclave hardening YTONG of the compressive strength class B3.5 and the density grade D500 on the adhesive composition Dryfix and were kept for 10÷15 days in the laboratory building under normal temperature and humidity conditions. After that, the samples were installed in a press with a capacity of 5000 kN. During the test, a scheme for fixing the samples in the upper and lower levels was adopted, corresponding to the hinge connection of the structure with the press supports. Hour-type indicators with a division price of 0,01 mm were installed on the prototypes to measure the vertical deformations of the masonry during their compression. The layout of the measuring devices on the samples and the general view of the sample in the press before the tests are shown in figure 4.

![Fig. 4. General view of the prototype before compression tests](image)

The load on the prototypes was supplied in stages amounting to ~10% of the estimated value of the destructive load. The interval between the loading stages was 5÷7 minutes. The method of data processing included the determination of the main normative parameters of the masonry, necessary both to determine its bearing capacity, and to identify indicators that characterize the features of the work of samples based on the use of cellular concrete blocks and glue.

In accordance with the instructions of SP 15.13330.2020 the bearing capacity of non-centrally compressed stone structures is determined by the formula:

\[ N_1 \leq m_g \varphi_1 R A_c \omega, \]

(1)

\( N_1 \) – destructive load during off-center compression;
\( m_g \) – the coefficient that takes into account the impact of a prolonged load. In the experiments carried out in this work, it is equal to one, because \( \eta=0 \) (table 21 SP 15.13330.2020);
\( \varphi_1 \) – the coefficient of longitudinal bending of the masonry, equal to one, because the flexibility of the masonry is less 4 (see the formula 15 SP 15.13330.2020);

\( R \) – calculated masonry resistance;

\( A_c \) – the area of the compressed part of the wall section with a rectangular stress plot:

\[
A_c = A \left( 1 - \frac{2e_0}{h} \right),
\]

\( \omega \) – the coefficient of the cross-section shape, determined by the formula:

\[
\omega = 1 + \frac{e_0}{h},
\]

Taking into account that during the compression of the masonry, there is a displacement of the load (the eccentricity of the force application) both along the sample (\( e_y \)) and across its cross-section (\( e_x \)), the area of the compressed zone was determined by the formula:

\[
A_c = A \cdot \psi \cdot \omega
\]

\[
\psi = \left( 1 - \frac{2e_x}{b} \right) \left( 1 - \frac{2e_y}{h} \right)
\]

For the possibility of comparing the masonry strength indicators of the prototypes of the I-th and II-th series at different load application eccentricities, the values of the compression stress in the masonry (tensile strength) were determined taking into account the reduction of the test results of the samples to the central compression:

\[
R_u = \frac{N_1}{A_c},
\]

The analysis of the results of experimental studies of the strength of masonry walls and piers made of cellular concrete blocks of autoclave hardening YTONG on the adhesive composition Dryfix allows us to note the following (table 2).

- The first hairline cracks in the masonry appear at loads amounting to 57÷67% of the destructive load, and the destruction of the prototypes itself was fragile.
- The ultimate strength (temporary resistance) at the central compression of the masonry was 3,42÷3,51 MPa. Taking into account the transition coefficient from the temporary resistance to the calculated \( k=2,2 \), the value of the calculated compression resistance of masonry made of cellular concrete blocks is \( \approx 1,6 \) MPa.
- Taking into account the experimental studies carried out, it is recommended that the calculated compressive resistance of masonry made of YTONG cellular concrete blocks of the B3.5 compressive strength class and the D500 density grade on the Dryfix adhesive composition produced by POLYPAG AG be taken equal to 1,6 MPa (16 kgf/cm²), which is higher than the value given in the current Norms for stone structures when using cement mortar.

**Table 2.** Results of tests of piers for central and off-center compression

<table>
<thead>
<tr>
<th>№</th>
<th>№ sam.</th>
<th>( N_u ) (kN)</th>
<th>( N'_u ) (kN)</th>
<th>( N_u / N'_u )</th>
<th>( R_u ) (MPa)</th>
<th>( e_x/e_y )</th>
<th>( \omega )</th>
<th>( \psi )</th>
<th>( R_u^m ) (MPa)</th>
<th>( R_m ) (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>C1-100</td>
<td>440</td>
<td>300</td>
<td>0,68</td>
<td>3,76</td>
<td>0,36/0</td>
<td>1,04</td>
<td>0,928</td>
<td>3,90</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>C2-100</td>
<td>400</td>
<td>250</td>
<td>0,63</td>
<td>3,39</td>
<td>0,68/0</td>
<td>1,07</td>
<td>0,864</td>
<td>3,67</td>
<td>3,51</td>
</tr>
</tbody>
</table>
3 Conclusions

Experimental studies of the strength and deformability of masonry walls were carried out using autoclave-hardened cellular concrete blocks manufactured by JSC «Kcell-Aeroblock-Center», manufactured using YTONG technology. The selling (passport) class of concrete blocks for compression is B3.5 with a density grade of D500.

The laying of the prototypes was carried out using the adhesive composition Dryfix produced by POLYPAG AG. The thickness of the seams in the masonry of the prototypes was 2÷3 mm.

Based on the analysis of the results of experimental studies of the strength and deformability of masonry walls made of autoclave-hardened cellular concrete blocks produced by JSC «Kcell-Aeroblock-Center» on the adhesive composition Dryfix produced by POLYPAG AG, under various force influences, as well as the instructions of table 11 note 4 SP 15.13330.20, the calculated masonry resistances, taking into account the above parameters of cellular concrete blocks and glue, should be taken equal:

1. The value of the temporary resistance to axial stretching along an unbound cross-section (normal adhesion) of the masonry of prototypes made of autoclave-hardened cellular concrete blocks made on an adhesive composition varied in the range from 0,23 to 0,32 MPa (on average 0,28 MPa). According to p.p. 6.14.4, 6.14.5 SP 14.13330.2018 for masonry of the I-th category of walls of buildings erected in earthquake-prone areas of the Russian Federation, the temporary resistance to axial tension must be at least R\text{tu} \geq 0,18 MPa. Taking into account the specified value of the calculated resistance of masonry from these blocks on the adhesive composition of Dryfix when designing buildings should be taken equal to 0,13 MPa. Taking into account the requirements of SP 14.13330.2018, to determine the category of masonry walls of buildings erected in earthquake-prone regions, the value of the temporary resistance to axial stretching of masonry along unbound seams should be taken equal to 0,28 MPa.

2. The value of the calculated tensile resistance of the masonry when bending along an unbound section should be taken equal to R\text{ex}_{tb1} = 0,18 MPa at the normalized value (table.11 SP 15.13330.2020) R_{t1}^{\text{norm}} = 0,25 MPa.

3. The value of the calculated tensile resistance of the masonry when bending along the bandaged section should be taken equal to R\text{ex}_{tb1} = 0,34 MPa at the normalized value (table.11 SP 15.13330.2020) R_{t1}^{\text{norm}} = 0,25 MPa.

4. The value of the calculated resistance of the masonry under central compression should be taken equal to R= 1,6 MPa. The normalized value of this value for masonry walls made of cellular concrete blocks of class B3.5 on cement mortar M50 according to the instructions of table.3 SP 15.13330.2020 is R_{t1}^{\text{norm}} = 1,3 MPa.

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