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Design features of facade cassettes from thin ceramics

Особенности проектирования фасадных кассет из тонких керамических панелей

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Ключевые слова: фасадные конструкции; кассетная облицовка; тонкая керамика; клеевое соединение; алюминиевые конструкции; вентилируемый фасад

Abstract. Thin ceramic plates are a promising material for architectural use which has significant potential for the realization of different interior and exterior solutions. The use of thin ceramics as facade cladding requires increased attention to the stress-strain state and the nature of its destruction. The main feature of this construction type is the ability to use facade panels with dimensions reaching 3000 x 1000 mm with a small weight and small thickness (3–5 mm). This research studies stress-strain state parameters of thin ceramic panels by testing on uniformly distributed load, simulating the wind effect on the cassette in conditions of the facade exploitation. As a result of laboratory tests obtained the dependence of the plate deflection on the action of a uniformly distributed load and identified convergence with the results of similar experimental work and theoretical studies. Also in this research was studied the work of facade structural sealants as part of facade structures: evaluated the effect of profile color, reinforcing mesh of plate and preliminary surface preparation with a primer on the adhesion to the cassette elements.

Аннотация. Тонкие керамические панели – перспективный материал для архитектурного использования, имеющий значительный потенциал для реализации различных интерьерных и экстерьерных решений. Применение тонкой керамики в качестве фасадной облицовки требует повышенного внимания к напряженно-деформируемому состоянию и характеру её разрушения. Основной особенностью конструкций данного типа является возможность использования на фасаде панелей с размерами, достигающими 3000x1000 мм, обладающими небольшим весом и малой толщиной (3-5 мм). Данное исследование посвящено изучению работы тонких керамических панелей под воздействием равномерно распределённой нагрузки, имитирующей ветровое воздействие на кассету в условиях эксплуатации на фасаде здания. В результате лабораторных экспериментальных исследований была получена зависимость величины прогиба пластины от действия равномерно распределённой нагрузки, получена сходимость с результатами аналогичных экспериментальных работ и теоретических изысканий. Также изучена работа фасадных структурных герметиков в составе фасадных конструкций. Исследованием оценено влияние окраски, усиляющей сетки и предварительной подготовки поверхности праймером на адгезионное соединение элементов кассеты.

Introduction

Exterior view of the building, which formed by facade elements, has a great importance not only for residents, but also for a large group of specialists, including architects, engineers and operating companies. In the design process, they need to provide compliance of aesthetic component and functional purpose of walling. Nowadays, to this list of tasks is increasingly added need for further research into new materials, used as facade cladding.

Today we have big variety of cladding materials: natural stone, brick, aluminum composite panels, different types of ceramic products and others. However, often from these types of materials we cannot

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make large details. For example, we can look on a residential complex, located on the Optikov Street in St. Petersburg, (Fig. 1). Here, designs chosen large-format elements, which based on the ventilated facade system. For such tasks and static conditions, we can apply only glass and thin ceramic panels, which have big original size, low thickness, lightweight and high strength to resist wind loading.

Figure 1. Project visualization (left)[3] and photo from the object (right) with thin ceramic cladding

Glass plates are widely used in building process as transparent elements of glass walls. It`s applying on opaque surfaces complicated by the high degree of reflection and high probability of scratching.

Thin ceramics (thickness is 3–6 mm, in some cases 10 mm), have many similar options with glass, like thickness and strength, except reflection, but this material researched not so widely as glazing. In particular, engineers do not have any information about static work of this material.

Also for this type of structures, big question is fixing to the supporting base. Constructions of this type usually have mechanical type of fastening – via clamp. Adhesive fixing is common rare [1]. In particular, it is possible to abandon the external aluminum frame, having carried out only on the adhesive bonding. Structures of this type is widely researched in [2, 3, 4] In addition, for large size panels is permissible to use combined systems of mechanical and adhesive type. This mechanical work panel for different system variants will be similar: a thin slab with hinged at the place of installation clamps or glue joints.

To perform detailed engineering, in the absence of full information about static properties of used material, there is a need for a study of thin ceramic plates to solve a group of questions, including:

1. Determine the influence of color on the adhesion of the sealant
2. Determine the influence of the reinforcing mesh on the adhesion of the sealant
3. Determine the influence of surface preparation of profiles on the adhesion of the sealant
4. Identify the influence of the thickness of the adhesive sealant on the bearing capacity of the joint
5. Indicate the actual type of plate fixing to the aluminum sub-structure
6. Determine the convergence of the results of the experiment on the uniform loading of the ceramic plate with similar tests and theoretical data
7. Investigate the mechanism of work and destruction of the panel construction

Materials and Methods

For the research the thin ceramic plate was used. Its distinguishing feature – is the slab size, which can reach up to 3000 mm in length, width has a maximum dimension – 1000 mm, with a relatively small thickness – 3 and 5 mm in unreinforced execution and 3.5 mm with reinforcement fiberglass (Fig.2). The panel made from a mixture of clay, feldspar, silica sand and mineral dyes and then pressed in a facility that does not restrict the acceptance form, to avoid creating stresses in the edge zones. Obtained sheet tempered in special furnaces at temperatures above 1220 °C, which ensures uniformity of the finished ceramic product. Follow cutting ensures exact compliance of panel dimensions for cassette elements.

[3] - Photo link: https://optikov.legenda-dom.ru

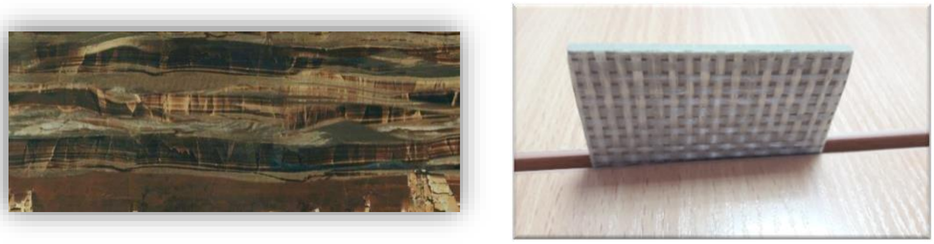


Figure 2. Example of the front surface (left)[4] and reverse side of the reinforced ceramic panel (right)

Detailed specifications of the material shown in Table 1. Here presented comparison of technical characteristics for thin ceramic panels and untempered glass.

Table 1. Characteristics of ceramic panels Laminam

№	**Physical and chemical properties**	**Test method**	**Requirements EN14411-G/ISO13006-G**	**Units**	**3.5 mm (with mesh)**	**5 mm (without mesh)**	**Glass (5 mm)**
1	Weight			kg/sq.m.	8.2	14	12.5
2	Water absorption	ISO 10545-3	<0.5	%	0.1 (<0.3)	0.1 (<0.3)	0.1
3	Dimensions of a slab			м	3x1	3x1	6x4
4	Bending strength in N/mm²	ISO 10545-4	≥ 35	N/sq.mm	90	50	45
5	Mohs scale hardness	UNI EN 101	-	-	≥ 6	≥ 6	≥ 6
6	Coefficient of linear thermal expansion / 10^{-6}/°C	ISO 10545-8	-	-	6.6	6.6	9
7	Elastic Modulus			MPa	55600	55600	70000

To carry out tests for determination of the bearing capacity and deformability of thin ceramic panels necessary to make loading by uniformly distributed load. As the test sample allowed using constructive scheme of facade cassettes. To form the facade element (cassette), which will be ready for testing, cladding panel installed in the aluminum profile. Fixation in the cassette is achieved by using of facade adhesive sealant. Constructive scheme of a cassette is shown on Figure 3 [5].

Taking into account work specifics of the thin plate elements, which applying leads to big deformation of panel surface – this fact determined chosen research methodology, based on the control of deflection value in the system.

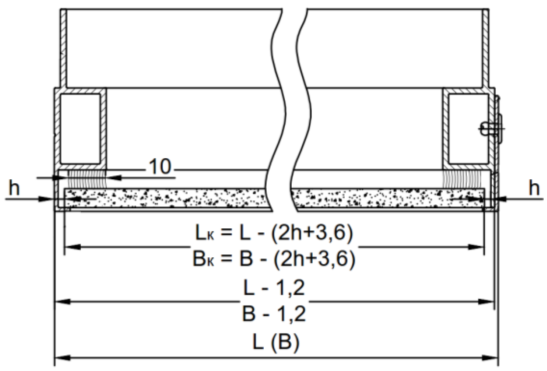


Figure 3. Constructive scheme of facade cassette

[4] - Photo link: http://www.laminam.it/ru/collections/1000x3000

The numerical and experimental research methods are used during the study of the structure static work.

In the numerical calculations was applied software, which uses finite element method in the embodiment of the displacement [6, 7, 8]. Structure modeling determines the theoretical values of the stress and displacement of system. As a calculative scheme was designated hinge plate, which is fixed by the four sides to cassette profiles. Based on a constructive solution, the cassette profile hinged fastened to the vertical mullions.

Stiffness of the vertical mullions and bearing brackets in the calculation not been evaluated. Bearing aluminum corners, which is situated at the top of cassette, is appointed as fixed supports. Hooks, which do not take the weight load, modeled as a vertical hinge (Fig.4).

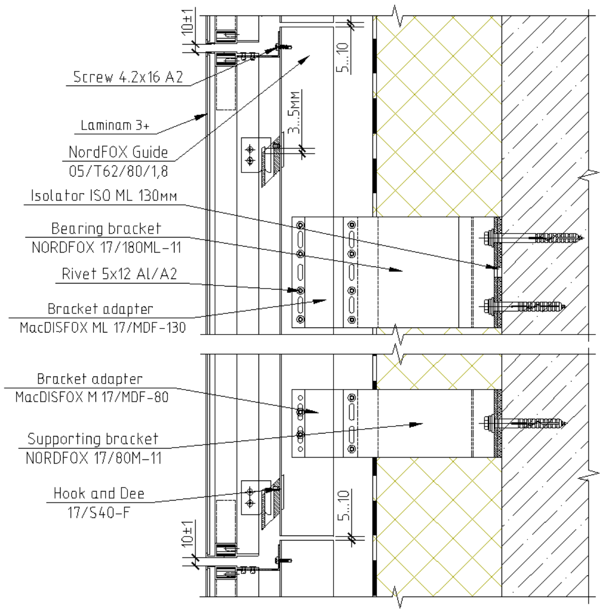


Figure 4. Section of facade system

The experimental method of investigation included several characteristic steps:

1. Test the adhesive joint on the bonding strength and compatibility

2. Testing the full-size cassette sample to the action of a uniformly distributed load

The first stage of experimental research was to test the strength of adhesive joints bonded materials (ceramic materials and aluminum frame) to determine the bearing capacity of the connection and purpose necessary and sufficient width of the sealant layer. At the same time, we determined the parameters for the compatibility of bonding surfaces: take into account paint coating on the profile (including a variety of colors), appointment of priming and cleaning the surface of profile and influence of deleting reinforcing grid in glue zones, as well as its influence on the load-bearing capacity of adhesive layer.

As the test samples were used fragments of the cassette profile with 100 mm length and standard width (16.5 mm) (Fig.5). A tensile testing machine with fixing the maximum value of the applied longitudinal force reached determination of the bearing capacity. The samples were prepared with different thickness of the sealant to determine the possible influence of this parameter.

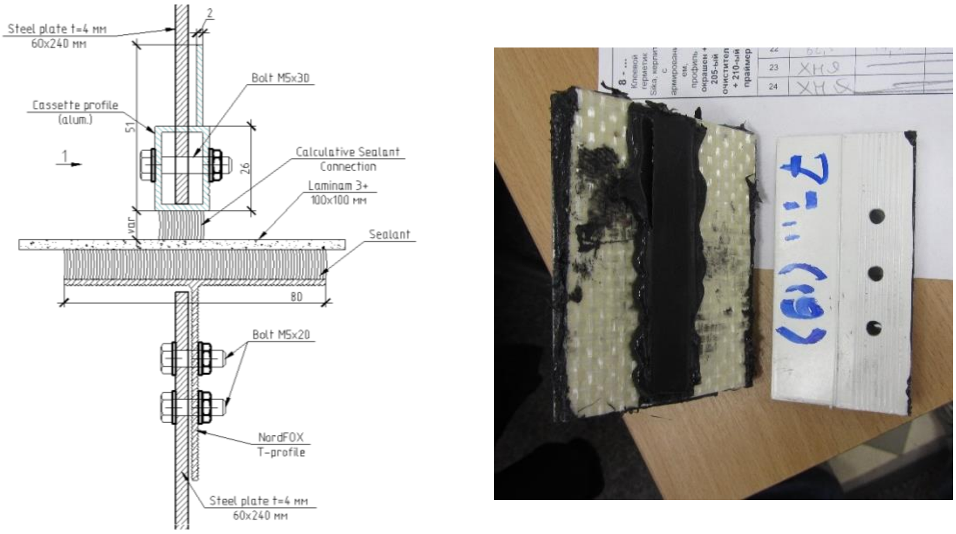


Figure 5. Testing scheme (left) and breaking results (right)

Research of compatibility and quality adhesive sealant adhesion to aluminum alloy 6060 made by CQP 033-1 – definition of adhesion and CQP 034-1 – the testing conditions in the determination of adhesion.

The tests of full-size samples carried out to determine the actual deflections of different cassette types (vertical, angular, horizontal with or without supporting beams) and compare it with the results obtained by analytical method [9, 10, 11], to identify the maximum bearing capacity and the nature of structural failure. During the test, was made an assumption about the possibility of loading the samples in a horizontal plane because of the small own weight cladding elements and aluminum profiles (Fig.6).

Figure 6. Testing stand (left) and deflectometer 6PAO (right)

On the test installation was mounted fragment of subsystem, which shown on Figure 4. Instead of concrete base, laboratory used traverses from I-beams (Fig.6). Uniformly distributed load on thin ceramic slab realized by gravel in measured package. Value of deformation was measure by several deflectometers (model 6PAO), fixed in the center of panel. Loading corresponded to a peak (gust) wind load at different height marks. Testing algorithm includes loading the sample to estimated maximum load (126 kg/sq.m for ordinary and 228 kg/sq.m. for corner zone of a building), then complete unloading and repeated loading until appearance of signs of the sample destruction.

In a laboratory were tested ordinary cassettes with sizes: 2700 x 1050 mm, 1100 x 1910 mm, corner type of cassettes with dimensions: 1100 x 1050 mm, 1050 x 1910 mm.

Comparison of the results proposed to carry out with a test of not tempered glass, which been loaded by uniformly distributed load with the help of the compression camera [12].

Results and Discussion

Results of test on bonding strength of the adhesive joint and compatibility

During tensile tests of samples obtained graphics of sealant deformation from applied longitudinal force under different conditions of applying sealant (Fig.7). Also, research determined influence of reinforcement grid on the load-bearing capacity in order to identify the need for its deletion in the field of gluing. In addition to this option, on the basis of value of the ultimate load, lab tests determines the minimum term for one or two-component sealant to reduce the time to start the mounting of cladding structures. Significant influence on the economics of the facade has adopted adhesive sealant thickness. According to [13], recommended minimum thickness is 6 mm. According to [14] – 3.6 mm value obtained by calculations (but minimal thickness by this document is – 5 mm for factory produced elements). During experiment was checked influence of the sealant thickness on bearing capacity of connection. Result values were summarized in the two tables (Tables 2 and 3), separated by production brand. Also test showed that unpainted profile had sufficient adhesion even without surface preparation. Primer pre-treatment applied to profile samples with powder painting. At the same time, be aware that a variety of colors and paint show different degrees of adhesion (as a result of the test was found a difference in the degree of adhesion of red (high) and white (low) color).

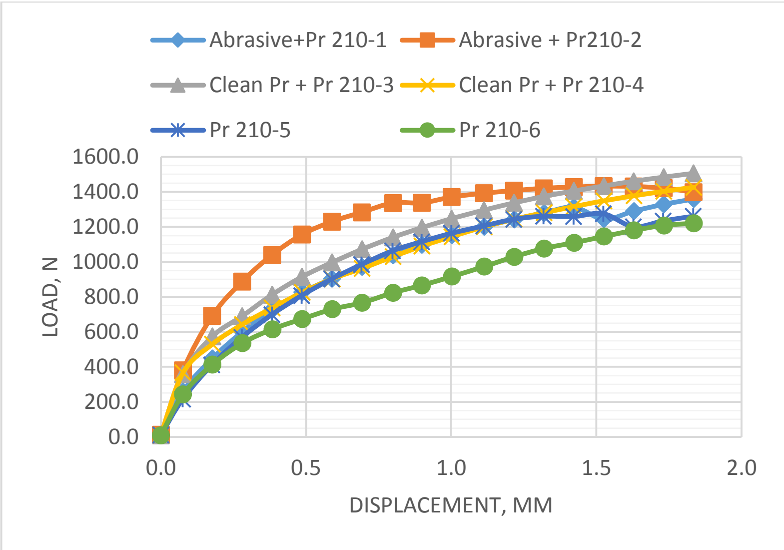


Figure 7. Testing stand (left) and deflectometer 6PAO (right)

Table 2. Characteristics of "Sika" adhesive sealant

Type of example	№	Joint parameters, mm			Breaking load, kg	Avg. Value, N	Avg. area, mm²	Calc. stresses, N/mm²
		Length	Width	Thick.				
Date of producing: 18/06/2014; Date of test: 23/06/2014								
Sika sealant (2 component), LAM3+, unpainted profile	1	87	18	6	152	1386	1392	0.996
	2	86	14	6	120			
	3	87	16	6	152			
Sika sealant (2 component), LAM3, unpainted profile	1	87	15	6	120	1439	1392	1.034
	2	86	14	6	144			
	3	87	18	6	176			
Date of producing: 18/06/2014; Date of test: 08/07/2014								
Sika sealant (2 component), LAM3+, painted profile	1	88	16	6	168	1099	1408	0.780
	2	88	11	6	72			
	3	86	13	6	112			
	4	88	13	6	96			
Date of producing: 03/03/2015; Date of test: 07/04/2015								
Sika sealant (1 component), LAM3+, painted profile	1	91	17	4	61	581	1424	0.408
	2	89	16	4	58			
	3	93	17	4	59			

Table 3. Characteristics of "Dow Corning" adhesive sealant

Type of example	№	Joint parameters, mm			Breaking load, kg	Avg. Value, N	Avg. area, mm²	Calc. stresses, N/mm²
		Length	Width	Thick.				
Date of producing: 23/06/2014; Date of test: 08/07/2014								
DC sealant (1 component), LAM3+, unpainted profile	1	88	15	6	184	1753	1305	1.343
	2	85	15	6	176			
	3	87	15	6	176			
DC sealant (1 component), LAM3, unpainted profile	1	87	15	6	176	1596	1305	1.223
	2	87	15	6	144			
	3	87	15	6	168			
Date of producing: 18/06/2014; Date of test: 08/07/2014								
DC sealant (1 component), LAM3+, unpainted profile	1	100	16	4	120	1046	1600	0.713
	2	95	16	4	128			
	3	100	16	4	101			
DC sealant (1 component), LAM3, unpainted profile	1	95	16	4	168	1465	1520	0.964
	2	94	16	4	120			
	3	91	16	4	160			
DC sealant (1 component), LAM3+, painted profile	1	81	16	6	72	810	1408	0.576
	2	88	16	6	80			
	3	93	16	6	96			
Date of producing: 03/03/2015; Date of test: 07/04/2015								
DC sealant (1 component), LAM3+, painted profile	1	89	16	4	72	526	1376	0.383
	2	88	16	4	40			
	3	86	16	4	49			

Results of numerical and experimental tests for full-size cassette samples

Research results are the values of displacements (Fig. 9), obtained by applied impact of uniformly distributed load on a full-size sample design (Fig. 8), and the maximum value of the wind pressure, which led to destruction of the sample (Table 4).

Analytical results have been obtained as a result of the static calculation of displacements (Fig. 9), which used as the basis for assigning a necessary step of strengthening cassettes by transverse or longitudinal (depending on the orientation of the cassette) supporting beams

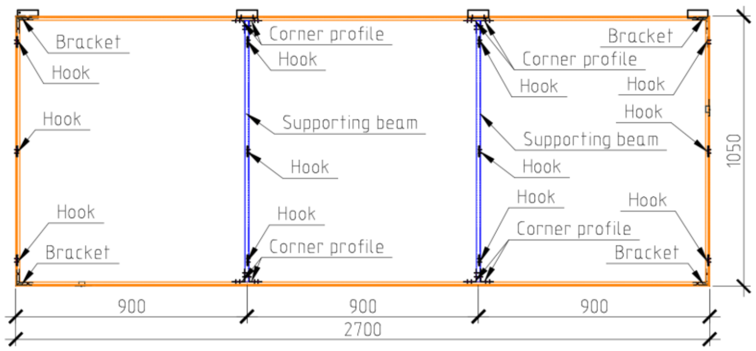


Figure 8. Example of cassette with dimensions 2700x1050 mm

The graph (Fig. 9) shows deflections of the center of panel with dimensions 2.7 x 1.05 m divided on 3 cell and 1.91 x 1.05 m, divided on 2 cell, obtained by the formula, reached in research of thin plates, was made in Samara University of Civil Engineering for glass panels, and during the experimental test [15]. In case these panels we have good repeatability of results.

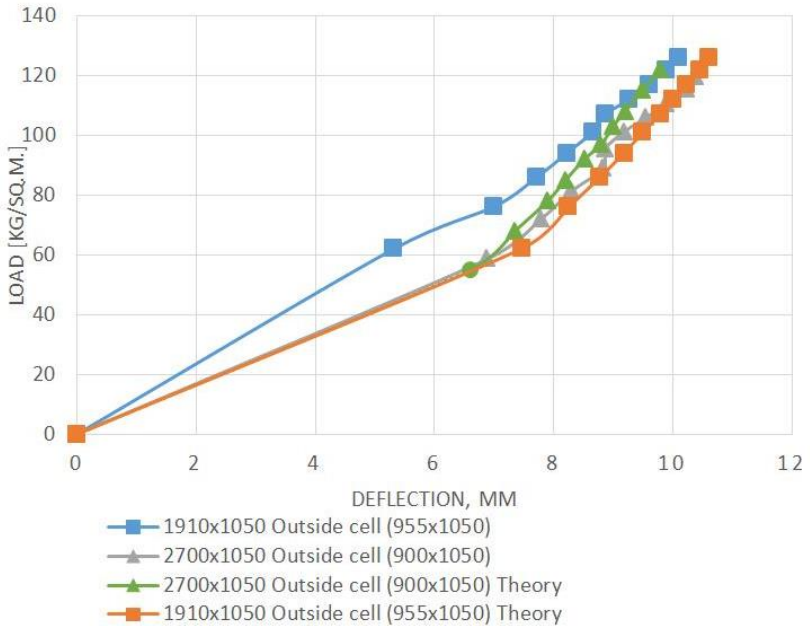
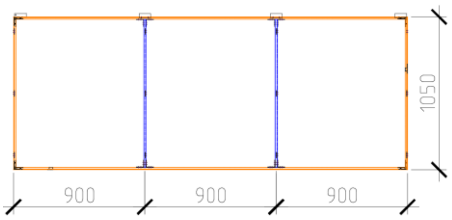
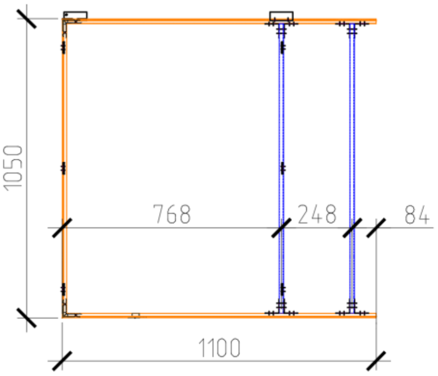
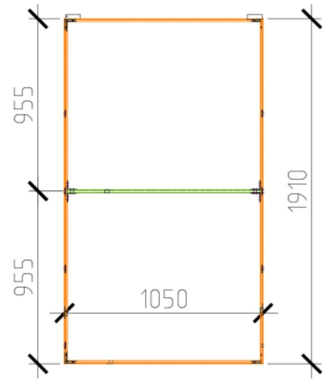
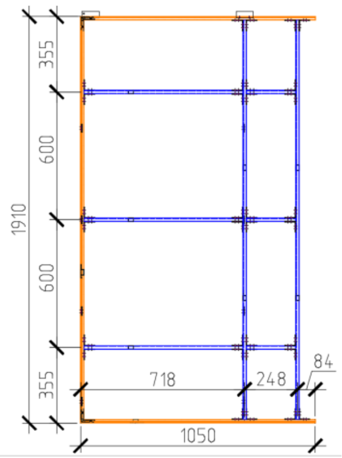


Figure 9. Test and theoretical calculation result

Table 4 summarizes test results of several types of cassettes used on the object:

Table 4. Results of full-sized breaking test for cassettes

№	Dimensions and characteristic of cassette	Sketch	Ultimate load, kg/m2	Max. deflection, mm	Theoretical deflection, mm
1	2700 x 1050, RAL 9016, normal		433.86	16.87	17.9
2	1100 x 1050, RAL 9016, corner		486.35	20	19.08
	1100 x 1050, RAL 9016, corner		463.47	19.46	18.65

<table>
<tr><th>№</th><th>Dimensions and characteristic of cassette</th><th>Sketch</th><th>Ultimate load, kg/m2</th><th>Max. deflection, mm</th><th>Theoretical deflection, mm</th></tr>
<tr><td>3</td><td>1050 x 1910, RAL 2002, normal</td><td>
</td><td>192.36</td><td>13.32</td><td>12.15</td></tr>
<tr><td rowspan="2">4</td><td>1050 x 1910, RAL 9016, normal</td><td rowspan="2">
</td><td>445.65</td><td>13.92</td><td>13.8</td></tr>
<tr><td>1050 x 1910, RAL 2002, normal</td><td>613.04</td><td>14.15</td><td>16.65</td></tr>
</table>

Analysis of the results shows that the design of the facade cladding, especially with adhesive sealants, it is necessary to take into account a number of factors that have a significant influence over the technical solutions.

Gluing of thin ceramics to the aluminum profile surfaces must be resolved by the tests for each object individually, as the color profile, the preparation of the slab or profile, and the presence or absence of reinforcing mesh, adjusts the bearing capacity of the connection

Based on performed research, can be made a conclusion that the greatest influence on the adhesive bond has a painting of the profile (reduction of load bearing capacity is 22 % for a two-component adhesive and 56 % for a single-component sealant). As a result, unpainted profile recommended using for facade constructions in places with hidden adhesive fixing and implementing mount directly to the pre-skim profile.

The inclusion of reinforcing mesh also has an effect on the connection: its presence reduces the carrying capacity by 4 % and 26 % for different types of sealants. Need to say, that work to remove this coating is rather hard and consuming a lot of time, that is why we expect, that version with not deleted mesh will be main in design calculation.

Reduced sealant thickness not directly affected on the load capacity under the action of tensile forces, but in this particular case of use in the cassette was performed departing from ETAG 002 recommendations regarding the minimum of sealant thickness (4 mm instead of the recommended 6 mm) and part of aspect ratio (4:1, instead of the recommended 3:1). A minimal thickness recommended by the manufacturers to make sure that a shear stress coming a differential thermal (temperature difference between the sealing and the installing of the panel) or structural movement that sealant can transfer. Moreover, the manufacturing process (pouring of the sealant) might require a minimum gap to assure that the silicone spreads correctly over the whole bite (width) of the joint [16, 17].

As a result, during the test, it has been identified reduction of bearing capacity, the average for the two producers up to 46 %. Specimens with a thickness of 4 mm in 10 % of cases showed break by adhesion failure, also inside the joint located cavity with the sealant having a viscous structure, it is indicating an incomplete set of strength including the twenty-day exposure. This phenomenon directly related to non-compliance with the proportions of sealant joint. However, the load-bearing capacity, demonstrated by adhesive is sufficient for the perception of wind loads, which used in the test bench.

Test results have shown good agreement with theoretical data of Volmir theory for thin plates and with the same tests carried out in Samara University of Civil Engineering for glass panels (Fig.10) [15, 18, 19]. Differences in the final test data for ceramic plates obtained because of the presence of backlash in the bearing brackets with rivet connections, crumple effect in aluminum because of tight contact with stainless steel fasteners and deformation of the aluminum cassette profiles between the fixing points.

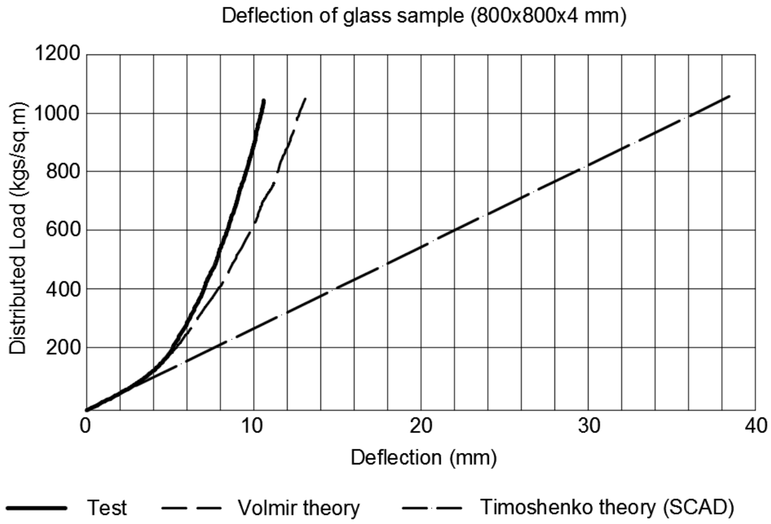


Figure 10. Results of glass plate test

As the result, formula for deformation of thin ceramics plates is:

$$f = a \cdot 10^{-4} \cdot (p)^{\gamma} \cdot 12 \cdot (1 - \mu^2) \quad (1)$$

where f – deflection of the middle of plate, mm

a, b – Long and short side of plate, mm

$$p = \frac{q}{E} 10^{-1} (\frac{b}{h})^3 \quad (2)$$

q – Uniformly distributed load, N/mm^2

E – Elastic modulus, MPa

h – Plate thickness, mm

μ – Shear deformation coefficient,

γ – Coefficient, depends on plate stiffness during loading.

Samples of the full-size cassettes that are involved in the tests, today approved on the real facades. Ordinary vertical cassette with sizes 1050 x 1910 tested to assess the possibility of increasing step of supporting beams up to 955 mm to economy the profile in production of cassettes of thin ceramic slabs.

Important note, that the destruction of the panel under the influence of uniformly distributed load carried safety in terms of the impact on pedestrians and vehicles: under the critical load, ceramics crack, but at the expense of reinforcement mesh action, cladding retains its shape and stay in place (Fig.11).

Figure 11. Destruction of cassette under the influence of distributed load

In this case, it may indicate the possibility of the timely replacement of the damaged panel without causing threats to human security. According to the results of research for full-sized cassettes was appointed a step of applying supporting beams in ordinary zone wind zone (850 mm) and in corner wind zone (680 mm) for conditions of Saint-Petersburg [20, 21].

The test results showed that bearing capacity of slabs from thin ceramics in 4.5 times more than the load, resulting in a maximum permissible deflection. In connection with this phenomenon appears the question of the rationality check of cladding structures from thin ceramic panels, glass or aluminum composite sheets on the critical deformations on the action of the peak wind load [22, 23]. This action has the effect of an emergency nature (hurricane, storm), does not lead to permanent deformations in the material of the panel and the frame and does not lead to technological malfunctions of the structure. Aesthetic psychological impact on the around people, during a hurricane, is limited by deflection designs which do not lead to the destruction, and this situation will not have influence on people.

In this connection, the authors offer to consider the possibility of making adjustments to existing regulations regarding check structures for deformations, based on foreign experience [24], which is the example of the German technical document divides the lining (in particular, glazing) on the vertical (Vertikalverglasung) less than 10° and horizontal (Überkopfverglasung) more than 10° deviation from vertical. For vertical glazing fixed on four sides, the deflection is not standardized, and for the horizontal is 1/100. For the horizontal glazing, fixed on three or two sides, the limit is 1/200 of the free edge length. This will allow produce more economical and at the same time reliable facade construction, because in Russian Federation for all types of structures on the aluminum frame, maximal deflection is 1/150 [20] for opaque surfaces and 1/250 for glass [25]. In addition, in this regard, it looks promising research at the Technical University of Darmstadt, regarding significant increase of the sealant hardness with the short-time loading, but loses this property with long-term action of load [26].

Conclusions

1. Unpainted profile has good adhesion even without surface preparation. Profile with powder painting needs primer pre-treatment. Different colors and paint methods has different degrees of adhesion.

2. In the course of the study, we determined influence of the reinforcing mesh on reducing the bearing capacity of the adhesive sealant by 4–26 % (depending on the manufacturer of adhesive sealant).

3. To ensure the adhesion of the adhesive sealant to the surface it is recommended to use a primer with an easy surface treatment with abrasive materials.

4. Reducing of sealant thickness has influence on bearing capacity and quality of adhesion. However, small adhesive thicknesses recommended using for two-component adhesive sealant (where aspect ratio of joint does not have influence). In other cases, recommended to use 5 mm minimal thickness.

5. In accordance with the test results, the hinge character of the fixing detected for the ceramic panel.

6. Test results have shown good agreement with theoretical data of Volmir theory for thin plates and with the same tests carried out in Samara University of Civil Engineering for glass panels.

7. The destruction of the panel under the action of a uniformly distributed load occurs because of the safe destruction of the ceramic plate (the expense of reinforcement mesh action, cladding retains its shape and stay in place).

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