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Optimization of External Render Formulations Based on Liquid Glass

Marijonas DAUNORAVIČIUS [1, 2] *, Violeta BIELIŪNIENĖ [2], Aldona RAGAUSKIENĖ [2], Edita SMETONAITĖ [2]

[1] *Department of Civil Engineering, Technologies, Kaunas University of Technology, Studentų str. 48, LT-51367 Kaunas, Lithuania*
[2] *Institute of Architecture and Construction, Kaunas University of Technology, Tunelio str. 60, LT-44405 Kaunas, Lithuania*

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This work focuses on the adjustment of formulations to determine the influence of the main component quantities on render properties. The purpose of the research is to create external silicate renders with high properties by changing the quantities of the main components of renders. The limits of the quantitative relations between the render components based within which the technical parameters of prepared renders and quality indicators of their coatings, were determined. The optimal binder and filler quantitative mass ratio was found. The exemplary composition of silicate render compliant with the said ratio is presented. It is a cost-efficient and general-purpose external render with good technological and technical characteristics.The tests performed correspond with the trends of development of the global industry of finish materials, i.e. the decrease in the quantity of organic components and the increase in the quantity of non-organic substances.

Keywords: liquid glass, silicate render, relationship between the quantities of render components and render properties, optimal quantative mass ratio of render components.

INTRODUCTION

Recently the trend to finish facades of insulated buildings with a decorative thin-layer render has become more dominant. The rendering process is extremely fast; such render is sufficiently efficient. The decorative render has to carry out not only an aesthetic function, but also to protect building partitions from harmful exposure of rain, wind and cold [1]. Therefore, the finishing coatings of the building facade insulation systems are subject for special requirements: they have to be resistant to atmospheric impacts, including chemically aggressive agents, have a good cohesion with a surface and have a great water vapour and gas permeability [2, 3]. Such requirements are partially satisfied by silicate finishing coatings of the mineral nature (render, paints), however, they are too water permeable, and they are not elastic and are not characteristic of high resistance to mechanical impacts. Besides, mixtures of such materials prepared for the use are not sufficiently stable. The render stability ensures a long duration of render storage and maintenance of the quality of formed coatings. Upon the use of polymer modifiers and stabilising additives, the stability of silicate paints related to silicate renders was significantly increased [4]. However, it has been determined that their quality degrades over time [5]. It is likely that such a trend is evident in the case of renders. Based on the research of a series of authors it may be stated that the properties of liquid glass determine thickening of substances with potassium liquid glass and degradation of properties [6, 7]. Liquid glasses are alkaline silicate solutions and consist of $Si(OH)_4$ silicate ions, polysilicate ions and colloidal silicic acid particles. They have prevailing dynamic equilibrium, which determines a structure and size of above mentioned particles. This equilibrium depends on liquid glass module (ratio of SiO_2 and K_2O clays), concentration, temperature, pH value, etc. Such solutions are thermodynamically unstable and due to dehydration they respond to condensate polymerization, which leads to formation of primary colloidal SiO_2 particles. At pH > 9 colloidal SiO_2 particles (sol) generate and grow fast – liquid glass coagulation is taking place. Subsequently, aggregation process – formation of viscous sols and gels – takes place [8]. Ate render is a dispersive system which combines solid, liquid and gaseous phases. A solid phase means fillers, pigments comprising structural framework the pores of which are filled by fine-dispersive particles and liquid phase. Colloidal-chemical properties of this liquid phase cohering solid particles and the content in the system determine the density of a thickened structure [9]. The structure density determines the strength of the thickened coating and permeability of water and vapour. Therefore the main technological task of the render coatings is to transform a primary coagulative structure of liquid glass into a dense condensate structure. The density of this condensate structure depends on a liquid glass silicate module and concentration of non-volatile substances (density) [10]. However, when the silicate module and density increase, the viscosity of liquid glass increases as well. Such glass, when compared to the glass of the lower module and density, is less stable; its mixtures are rapidly thickening even with inert powder substances, and the glass may coagulate [11]. However, in case the module and density are lowered too much, it will be difficult to produce strong and water-resistant coatings [12, 13].

*Corresponding author. Tel.: +370-37-351627; fax: +370-37-451355.
E-mail address: *marijonas.daunoravicius@ktu.lt* (M. Daunoravičius)

Therefore it is necessary to determine the values of the liquid glass module and density by testing, which allow producing renders with optimally combined operating stability and technical indicators of their coatings.

The render compositions generally contain non-organic pigments, carbonate, silicate, phosphate and sulphate fillers as well as stabilizing, dispersible and rheological additives [14, 15]. An important component is fillers which not only have to ensure render consistency, spreading rate, operating properties of thickened coatings, but they may also increase the render efficiency. However, the effect of earlier mentioned components, especially that of fillers and pigments, on the properties of silicate renders has not been thoroughly examined and is not clear yet. Therefore it is necessary to carry out analyses of silicate render properties and composition, determine optimal quantitative relations of the main components and thus create assumptions for optimization of the render compositions. Having determined the limits of the quantitative relations of the main render components, within which good process parameters of the renders are ensured as well as high indicators of the render stability and their coatings, it is possible to produce compositions of silicate renders, which are compliant with the quantitative relations. It has been determined that when changing the quantities of the main components of silicate paints (modified binder, fillers, pigments) within the optimal limits, it is possible to change significantly the main technological properties of paints and operational properties of their coatings, i. e. water and vapour permeability, mechanical strength of dry and wet coating and the strength of its cohesion with the surface [16]. By analogical correction of the compositions of silicate renders and direct changing of their properties it is possible to produce not only universal compositions with all sufficiently high-value properties, but also the renders with the certain extremely high-quality special properties. When generating compositions of such renders it is required to follow the provisions that in order to produce renders with a set of special property, it is necessary to maximize (minimize) the content of a component affecting this property without infringing its optimal quantitative relations with the other components of the composition.

The objective of this work is to determine optimal parameters of a silicate render binder – potassium liquid glass – and quantitative relations of the main render components by carrying out tests and produce renders with optimally corresponding stability and technical-operational indicators of the coatings on the basis of said relations.

MATERIALS AND METHODS

Potassium liquid glass of (1120 – 1260) kg/m^3 density and 1.5 – 4.5 silicate module was used during the tests. Liquid glass was modified by styrene/acrylic polymer dispersion Finndisp A 11, particle size 0.19 µm, pH 7.5 – 8.5, MFFT 14 °C, content of non-volatile substances – 50 %. Due to the electrostatic effect of a carboxylic group this dispersion not only stabilizes the binder, liquid glass, but also reaglomerates pigments and fillers.

During the previous tests it was determined that mineral pigments, titanium, ferric, chromium oxides, were most suitable for silicate compositions [17]. The characteristics of mineral pigments resistant to alkaline and light used in these tests are provided in Table 1.

Table 1. Pigments used for renders and their characteristics

Title	Chemical composition	Colour	Medium particle size, µm
Red ferric oxide (hematite)	Fe_2O_3 (up to 95 %)	Dark red	0.17
Yellow ferric oxide	Fe_2O_3 (< 84 %)	yellow	0.7
Chromium oxide	Cr_2O_3	green	0.30
Titanium dioxide	TiO_2 (rutile)	white	0.10

When selecting fillers their properties have to be taken into account. Some minerals – calcite, kaolin, baryta – may improve decorative properties of the coatings but degrade mechanical ones. The others (quartz, mica), on the contrary, improve physical-mechanical properties but degrade decorative ones [18]. Therefore several types of fillers, for instance, 2 or 3 combinations of different fillers, instead of one type should be used. It is stated that talc improves all properties of the coatings (decorative, physical-mechanical, technological and operational), therefore it can be used in all cases [19]. The characteristics of micro-fillers used during the tests are provided in Table 2.

Table 2. Characteristics of micro-fillers used for renders

Micro-filler	Chemical formula	Shape of particles	Medium particle size, µm
Talc	$3MgO·4SiO_2·H_2O$	Plates	10
Calcite	$CaCO_3$	Spheres	6
Calcite	$CaCO_3$	Spheres	10

Larger fillers are also necessary for the renders. They influence the thickness of the formed coatings and make their pattern. The marble granules of 1 mm – 2 mm thick were used during the tests. The following additives ensuring the required technological and technical painting characteristics were used in the render compositions as well: glass stabilizers, viscosity converters, thickeners, dispergators, antifoamers and emulgators. When using the provided substances a test composition of a render was produced, where fillers comprised 70 percent of the mass (35 % of micro-fillers and 35 % of larger granules), polymeric dispersion – 5 %, liquid glass and water – 7 %, pigments – 5 %, additives – 3 %.

1. Analysis of the renders of a liquid phase:

– *render consistency* was determined only after the render preparation and exposure of the different duration. In order to intensify the processes involved in the mixtures and thus reduce the duration of exposure, they were kept in a sealed container at the increased (40 °C) temperature. The consistency was assessed by plunger penetration based on the methodology defined in the standard LST EN 1015-4:2004 [20].

Analysis of hardened render coatings:

– *abrasion-resistance of the render coatings* was determined according to LST EN ISO 7784-2:2006, by means of applying the Taber method using 10 mm thick concrete plate samples with formed and hardened render coatings [21].

– *resistance to water* is assessed by a softening coefficient – at a ratio of coating resistance to abrasion in a wet and dry state. Coating resistance to abrasion has been determined applying the Taber method.

– *wet-scrub resistance* – 2 mm thick render coatings were formed on the window glass plates. Subsequently, they were tested by means of the device of the company "Braive instruments" according to the methodology defined in the standard LST EN ISO 11998:2006 [22].

– *resistance to weathering impacts* – 2 mm thick render coatings formed on the glass plates were artificially aged in the apparatus QUV/ spray with UVA 340 lamps. The test cycle consisted of 5 h of luminos discharging and 12 min. of overhead irrigation. The samples were inspected every 20 test cycles. During the inspection the following common coating defects were detected: peeling, rupturing, cracks, blistering, chalking, contamination, colour change. Chalking is the release of easily removable fine powder on the surface of the render coating upon degradation of its one or several components, most frequently the binder. Chalking products are removed from the coating by means of a sticky band. The chalking products attached to it were tested in the contrast background. The chalking level and other coating degradations were assessed according to the sample standard pictures and standard scales specified in parts 2 – 5 of the standard LST EN ISO 4628 [23].

– *vapour-permeability of render coatings* was determined by using gypsum plaster plate samples according to LST EN ISO 7783-2:2002. The 2 mm thick coatings formed on the plates. After 14 days the samples were tightly installed on the glasses with water. The glasses with the samples were placed in the test chamber where temperature and humidity are controlled. During certain periods of time glasses with the samples were weighted and the density of the vapour flow through the paint coating was estimated according to LST EN ISO 7783-2 [24].

– *water permeability* was determined according to LST EN 1062-3:2008, using 3 cm thick and 225 cm^2 standard concrete plates with the formed 2 mm thick render coatings, which were being cured for 14 days [25].

– *cohesive strength by removing* paint coatings from concrete plates using device 58-C0215/T of the company *CONTROLS* was determined according to LST EN 1504:2004. Test renders were applied onto the dry standard concrete plates with the 2 mm layer [26].

All samples of tests were cured for 14 days under the conditions of (21 ±2) °C temperature and (60 ±10) % of relative air humidity.

RESULTS AND DISCUSSIONS

During the first phase of the work the effect of a binder – potassium liquid glass – on the stability of render test compositions, physical mechanical and operating properties of their coatings was analysed. The dependencies of the stability of render mixtures, resistance of thickened coatings to water and mechanical strength dependence on the liquid glass module and density were determined.

In order to determine the impact of potassium liquid glass on the stability of render mixtures the render mixtures of the test composition were stored in a sealed container at the temperature of 40 °C. When stored under such conditions the mixtures were visibly thickening. The thickening rate was increasing by increasing the liquid glass silicate module (Fig. 1).

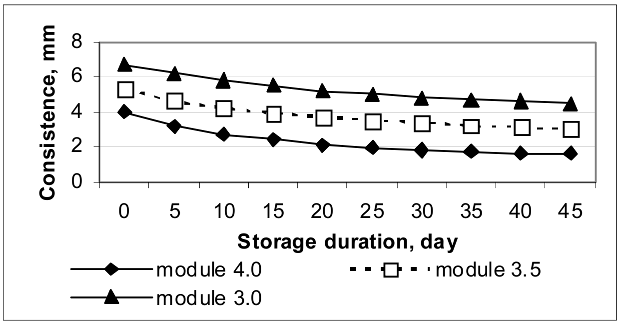

Fig. 1. Dependence of a thickening rate of silicate renders at the temperature of 40 °C on the liquid glass (density 1200 kg/m^3) silicate module

The render starts thickening extremely fast when the liquid glass module increases up to 4 and density exceeds 1200 kg/m^3. Therefore it is unreasonable to use the high concentration (over 1200 kg/m^3 of density) glass, since in such a case the render stability significantly decreases and liquid glass is used inefficiently. The same trend is observed when the liquid glass module is increasing, especially when it exceeds 4. This shows that in order to ensure stability of prepared renders liquid glass of the module lower than 4 and of density not exceeding 1200 kg/m^3 should be used.

However, it is necessary to assess dependencies of properties of thickened render coatings, especially those of resistance to water and mechanical strength, on the parameters of liquid glass. An important indicator of thickened render coatings – resistance to water – is evaluated by a softening coefficient, i. e. a ratio of resistance of wet and dry coatings to abrasion. Coating resistance to the water impact is also shown by their wet-scrub resistance. These indicators show a degree of weakening of impregnated coatings which has to be as low as possible.

Upon the analysis of resistance of thickened render coatings to water, an explicit improvement of this property at the increase of the liquid glass module has been determined (Fig. 2). The coating weakening is insignificant when the liquid glass silicate module is higher than 3.5 and in case the module is lower than 3, the coating weakening greatly increases (a numeric value of the softening coefficient decreases). The same trend is confirmed by tests of the coating wet-scrub resistance (Fig. 2).

When changing the density of liquid glass it is possible to adjust coating resistance to abrasion and the strength of cohesion with a surface. Figure 3 shows that when increasing the liquid glass density, the coating resistance to abrasion and cohesion strength are increasing and liquid glass of 1180 kg/m^3 density ensures a quite high level of the strength of cohesion with the surface – 1.4 MPa – as well as 4.5 mg/rev resistance to abrasion.

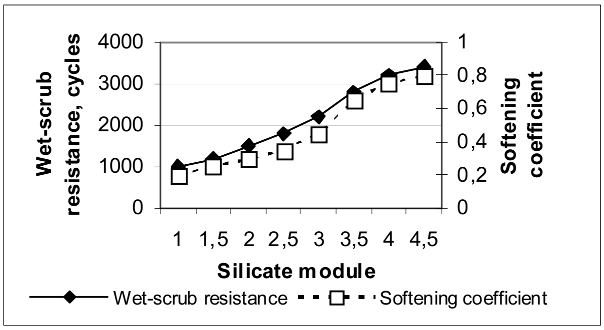

Fig. 2. Dependence of silicate render coating resistance to water and wet-scrub resistance on liquid glass (density 1200 kg/m^3) silicate module

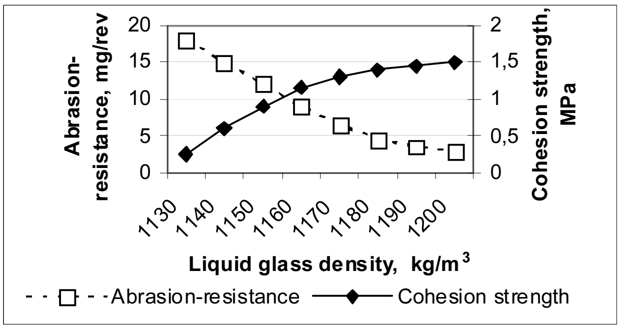

Fig. 3. Dependence of the cohesion strength and abrasion-resistance of silicate render coatings on the liquid glass (silicate module 3.5) density

When varying liquid glass density and silicate module it is possible to combine optimally the water-resistance of the cured render coatings and mechanical strength. The achieved results showed that it was most rational to use liquid glass of 3.5 – 4 module and (1180 – 1200) kg/m^3 density for the renders. When using the industrial liquid glass of a different density, the water amount is selected which dilutes liquid glass reaching an optimal density level.

In order to determine the effect of a pigment modification and content to the tested renders, the ratio of masses of pigments and micro-fillers (P/F) was changed in a tested silicate render composition by maintaining an equal total mass. The samples of the cured render coatings were aged in an accelerated way using the apparatus QUVspray and their degree of chalking was determined.

Figure 4 shows that at the relative increase of the amount of pigments the degree of chalking also increases. For this reason the amount of pigments cannot exceed 0.4 of the filler mass. This amount includes TiO_2, which is necessarily used in all compositions, and in separate cases, colour pigments are used. Since a part of pigments less than 0.2 does not paint renders sufficiently, an optimum content of pigments in render compositions should comprise 0.2 – 0.4 of the filler mass, or the P/F ratio should be within the limits of 1 : 5 – 1 : 2.5.

It is stated [27] that when increasing the amount of a binder in paint compositions it is possible to achieve the reduction of coating contamination, degree of chalking, the increase of resistance to mechanical exposures and the increase of water impermeability. However, the negative outcomes of the increase of the binder content may also emerge: the decrease of vapour permeability, stability decrease when storing and degradation of spreading rate.

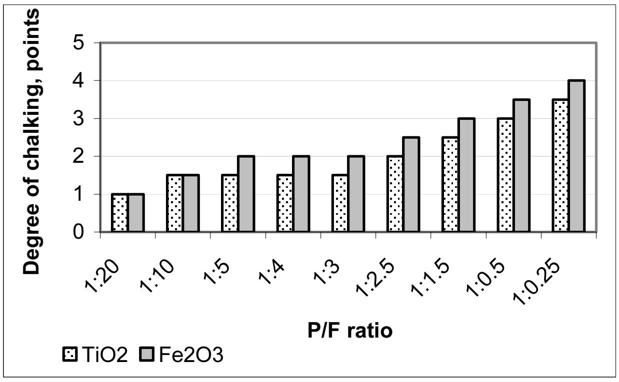

Fig. 4. P/F ratio effect on chalking of render coatings aged for 720 h

Therefore a correct selection of the ratio of a binder with pigments and fillers is a very important factor of the quality of paints and renders. The quality is determined by optimal density of fillers' packaging up and formation of a strong and water-resistant structural framework. This ratio will be referred to as B/PF. This is a ratio of the total mass of non-volatile substances of liquid glass and dispersion with the total mass of a pigment and filler. A series of render compositions with different B/PF ratios were tested (Table 4).

Table 4. Compositions of test renders with different B/PF ratios

Item No	Name of component	Composition options (content, masses %)							
		I	II	III	IV	V	VI	VII	VIII
1	Water and additives	15	14	13	12	11	10	9	8
2	Pigments	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5
3	Fillers	71	72	73	74	75	76	77	78
4	Polymer dispersion	6	5.5	5	4.5	4	3.5	3	2.5
5	Liquid glass	6.5	6	5.5	5	4.5	4	3.5	3
	B/PF ratio	1:6	1:6.5	1:7	1:8	1:9.5	1:11	1:13	1:16

B/PF ratio is the ratio of the binder mass (liquid glass and dispersion non-volatile substances) with the total mass of a pigment and fillers.

The dependences of different properties of render coatings of these compositions on the B/PF ratio were determined. At the increase of this ratio the water vapour and water permeability increases (Fig. 5).

However, if B/PF exceeds 1 : 13, the mechanical strength of the coatings starts decreasing rapidly, which is illustrated by the decrease of the cohesion strength and abrasion-resistance (Fig. 6).

In case B/PF ratio exceeds 1 : 13, it results in the increase of the degree of chalking of the render coatings (Fig. 7).

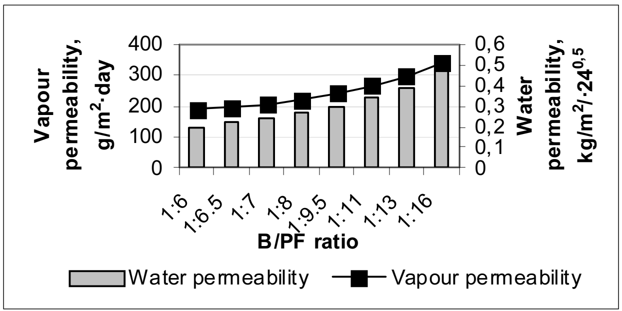

Fig. 5. Dependence of water and vapour permeability of render coatings on B/PF ratio

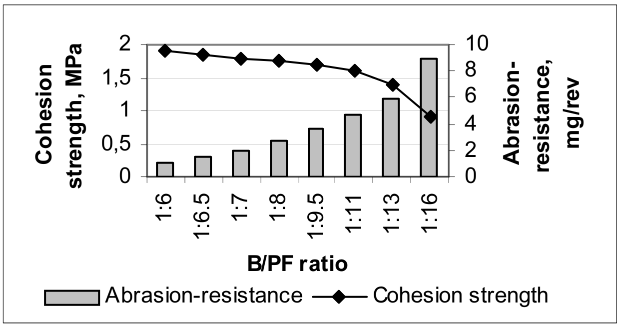

Fig. 6. Dependence of the cohesion strength and abrasion-resistance of silicate render coatings on B/PF ratio

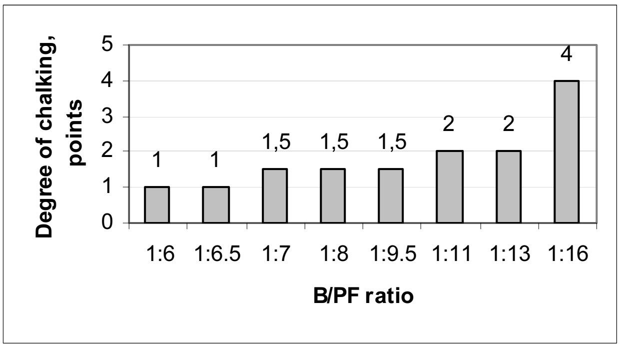

Fig. 7. B/PF ratio effect on chalking of renders coatings aged for 720 h

On the basis of the achieved results the following conditions for developing optimal compositions of silicate render were defined:

potassium liquid glass has to be of around 1180 kg/m^3 of density and have the 3.5 – 4 silicate module. Its content (non-volatile substances) has to comprise 3.5 % – 4 % of the total render mass;

dispersion content (non-volatile substances) has to comprise 3 % – 3.5 % of the total render mass;

pigment and micro-filler mass ratio has to be within the limits of 1 : 5 – 1 : 2.5;

silicate binder (non-volatile substances of liquid glass and polymeric dispersion) mass ratio with the total pigment and filler mass has to be 1 : 11 – 1 : 13. In order to produce the coatings possessing the increased mechanical strength, the binder content may be increased up to 1 : 10.

In compliance with the established conditions for development of optimal render compositions a exemplary composition of a render was designed (Table 5).

Table 5. Exemplary composition of the silicate render compliant with the optimal quantities of components

Item No	Component	Content, masses %	Render coating property
1	Water	7.0	Vapour permeability 240 g/m^2·day; S_d = 0.09 m; Water permeability 0.37 kg/m^2·24$^{0.5}$; Wet-scrub resistance 5800 cycles; Resistance to abrasion 20.4 mg/rev; Strength of cohesion with concrete 1.4 MPa; Chalking 3 points; Drying time 60 min; Full drying time 72 h
2	Liquid glass	10.5	
3	Polymer dispersion A11	6	
4	Micro-filler 10 μm	12	
5	Micro-filler 5 μm	18	
6	Micro-filler Talc	5	
7	Fibre micro-filler	0.5	
8	Pigment TiO_2	8	
9	Larger filler 2 mm	31	
10	Dispergator	0.1	
11	Silicate stabilizer	0.3	
12	Thickener	1.3	
13	Antifoamer	0.2	
14	Emulgator	0.1	

It contained the liquid glass of 1260 kg/m^3 density (non-volatile substance concentration 35 %) and 3.5 module. The content of liquid glass in the composition (non-volatile substances) – 3.67 %, polymeric dispersion (non-volatile substances) – 3.0 %. Pigment and micro-filler mass ratio was 0.23. The ratio of non-volatile substances of liquid glass and polymeric dispersion with the total mass of pigments and fillers equalled to 1 : 11.2. The quantities of additives were chosen on the basis of the manufacturers recommendations.

CONCLUSIONS

1. It has been determined that the binder – liquid glass – is responsible for the stability of silicate renders and the strength properties as well as water-resistance of the coatings. When its module and density increases, the render coating strength and water-resistance increase as well, but at the same time, the render stability decreases. In order to produce renders with optimally consistent properties it is necessary to use potassium liquid glass of 1800 kg/m^3 – 1200 kg/m^3 density and 3.6 – 4 silicate module.

2. The effect of mineral pigments on the stability of silicate renders and chalking of their coatings has been explained. The optimal quantitative relation between pigments and fillers has been determined. At the relative increase of the pigment content the degree of chalking of render coatings increases. Therefore the pigment content cannot exceed 0.4 of the filler mass, and the share less than 0.2 does not paint the renders sufficiently. Therefore the optimal pigment content should comprise 0.2 – 0.4 of the filler mass, or the ratio of the pigment and filler masses should be within the limits of 1 : 4 – 1 : 2.5.

3. The optimal ratio of the masses of the binder (liquid glass and dispersion non-volatile substances) and fine-dispersive render components (micro-fillers with pigments) has been determined. At the increase of the binder content the coating chalking decreases, however,

vapour permeability and render stability when storing degrade. The ratio of the binder and masses of fillers and pigments enabling to optimally harmonize the properties of the render stability, coating resistance and vapour permeability equals to 1 : 11 – 1 : 13. In some cases, the binder share may be increased up to 1 : 10 in order to reduce render chalking.

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