# The plasma-chemical methods of decorating foam glass surface

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**Abstract.** Nowadays one of the most promising directions in building industry is developing a resource-saving technology of producing new glass-composite building materials, efficient in saving the energy resources, spent for providing and maintaining the necessary temperature conditions indoors. The raised requirements to the heat insulation of buildings pose for technologists and designers the new problems concerning improving the heat retention properties of materials, used in building industry. The article describes the factors, having influence on the intensification of pore-formation processes and on the high-porosity heat-insulating materials structure formation. There were developed the technological schemes of depositing plasma-chemical coatings onto the foam glass surface. The microstructure of the received glass composite was studied with an electron microscope MIRA SCAN and X-ray phase analysis. The mechanism of plasma-chemical coatings formation on the surface of heat-insulating glass composite was found out, and it was determined that the adhesion of coating with the underlayer is conditioned by the formation of contact layer, having the vitro-crystalline structure, due to the diffusion of the coating's components into the underlayer at the plasma-chemical treating of the foam glass surface in the system underlayer - coating – plasma-chemical medium.

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## Introduction

At present the application of foam glass in building industry is limited by a number of factors [1]:

- the relatively high price of the material;
- the lack of normative base concerning foam glass (national standards for products, testing and control methods for foam glass etc.);
- the lack of manufacturing facilities, which could fill the need for heat and sound insulation of large building projects;
- the lack of design and engineering development, substantiated by engineering calculations, for producing the foam-glass heat-insulating and sound-insulating materials, which could be used by architectures and constructors in their project works.

The main one is the first factor, which, actually, hampers the development in the other respects.

The tendency of the recent years is trying to make the material cheaper by additional charging of foam-forming mixtures with technogenic waste (scums of metallurgical plants, CHP plants ash etc.), local raw materials (diatomites, perlites, zeolites etc.) [2,3,4]. The adding of these materials to foam glass mixtures, results in fractional or total crystallization and, as a consequence, in the decrease of heat-insulation characteristics and the increase of sponging temperature to 900-1200 $^0$C. So, to lower the melting temperature, one has to use a rather expensive boron-containing raw stuff, and in this case the economy from the partial replacing of waste glass is neutralized by the high power consumption and the expensive conditioned raw material.

So, the foam glass must be provided with such properties, which would not only characterize it as a heat-insulating or sound-insulating material, which requires covering with protective or decorative layers to be used in construction, but as a glass composite, having the decorative properties of glazed ware (like, for example, ceramic tile) and not requiring any additional protective layers against the atmospheric action [5, 6].

## The main part

For producing the glass composite the foam glass was used as an underlayer and for depositing the plasma-chemical composites the specially designed schemes of decorating were used.

The high-quality heat-insulating material is characterized by the uniform distribution of pores in the bulk of the mateial and fine-porous texture. The shape of pore structure depends on the extent of porosity, technological parameters and methods of material production [7].

The heat conductivity of vitreous materials is lower than that of crystalline materials, as the average distance of elastic wave in them amounts only to several interatomic spaces. In vitreous materials the phonons' free path length alters slightly with the increase of temperature due to irregular disposition of atoms and phonons dispersion.

We have developed a generalized scheme of depositing coatings on the foam glass by using plasma-chemical methods (fig. 1).

According to the developed scheme, the one-stage and two-stage plasma-chemical methods of depositing coatings onto the foam glass surface were used in this work [8,9]. The simplest and the least power-consuming are the one-stage plasma-chemical methods.

The two-stage methods allow getting a wider color range of coatings, but they are more expensive, as they are presented by a combination of one-stage ones.

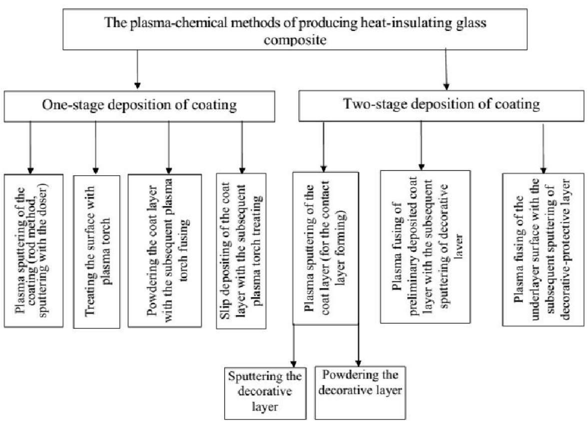


**Fig. 1. The plasma-chemical methods of depositing coatings onto the foam glass surface**

The deposition of coating by method of powdering doesn't include the stage of drying the coating, which is necessary at the slip deposition of coating. At powdering the frit must have the appropriate fusibility characteristics (high flowability and wetting force, low surface tension). Methods of coating deposition by powdering and slip deposition are very similar in their technology.

In order to study adhesion between coating and foam glass the glass composite was researched by electron microscope (fig. 2).

The analysis of photomicrographs confirms the presence of the contact layer in the composite material, which is 150-300 µm thick. By means of X-ray phase analysis there was studied the composition of contact layer foam glass-coating.

As a result of analyzing the diffraction peaks in the X-ray pattern of a sample of contact layer foam glass – coating on the base of plate glass waste (fig. 3.) there was determined the presence of amorphous phase, and, presumably, the following crystalline phases: calcium aluminosilicate $CaOAl2O_36SiO_2$ (d/n, Å: 3,214; 3,739; 3,356; 3,739); sodium aluminosilicate (nepheline) $NaAlSiO_4$ (d/n, Å: 3,02; 3,86; 3,28; 4,2).

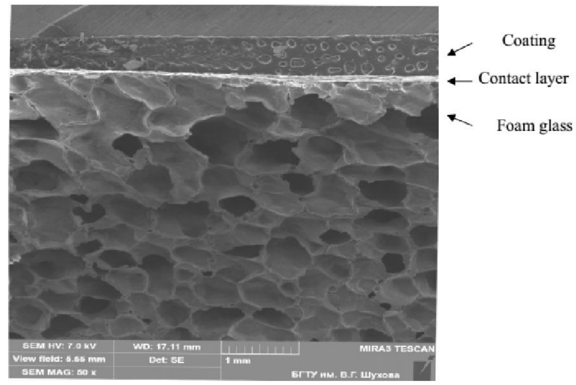


**Fig. 2. The microstructure of glass composite (fusion method)**

By comparative analysis of X-ray pattern (fig. 3) it was found out that the contact layer between coating and underlayer is the glass phase, penetrated with crystalline phases, which are formed at the interphase boundary coating - foam glass.

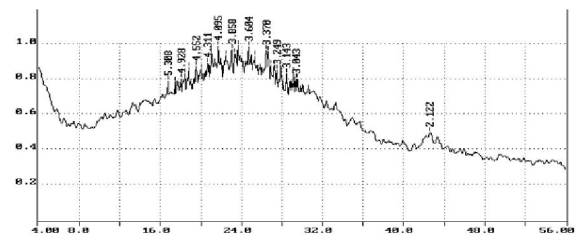

**Fig. 3. The contact layer foam glass-coating**

The surface of a highly-porous material (foam glass) is well developed, which increases the bond (adhesion) strength of coating and underlayer.

The similarity of coating (waste glass) and underlayer (foam glass) composition provide adhesion due to chemical and electrochemical reactions, dissolving, diffusion etc. The alteration of interphase boundary relief, the formation of new products, i.e. the forming of new intermediate layers, which are a specific feature of adhesion, is confirmed by photomicrographs of samples [10].

The quality of coating (i.e. the process of glass layer compaction at its baking and diffluence) is influenced by the following factors:

- viscosity;
- surface tension;
- density of the fused coating (at first the increased surface tension of the fused glass and its relatively low viscosity promotes the decrease of gas content, and then, with the increase of the fused glass

density, there raises the buoyancy force, affecting the gas bubbles);

- correlation of coating and underlayer TCLE values;
- diffluence of fused coating;
- adhesive strength with the underlayer.

At depositing the plasma coatings an essential role is played by the diffusion. At the temperatures of plasma-chemical treating of the surface the diffusion processes go intensively at the boundaries underlayer–coating–plasma-supporting medium.

The mechanism of coating formation was studied according to the method of depositing the coating:

- at treating the coating, preliminary deposited onto the foam glass surface, with plasma torch (fusion);
- at depositing the coating, preliminary rod-shaped and fused in the plasma torch, onto the foam glass surface (sputtering);
- at melting the foam glass surface with plasma torch (partial melting).

Scheme first coating process (melt) can be represented as follows.

On the surface of the underlayer (foam glass) there was deposited a coating layer, consisting of plate glass waste, and including liquid glass as binding substance. To reduce thermal shock the samples were preheated in muffle furnace to the temperature 350-400 $^0$C. Within this period the remaining moisture, which has not been removed in the process of drying, evaporates intensively from the coating layer. At the plasma treating of the surface there take place the fusion of the coating and, due to dynamic pressure, the intensive diffusion processes between the fused coating and surface layers of the foam glass [10].

The similarity of the coating and underlayer chemical composition provides the similarity of their main technological characteristics: TCLE, viscosity, surface tension etc. With the cooling of fused glass there are formed three layers of composite: the coating, the contact layer and the underlayer (foam glass). The contact layer provides the adhesion of underlayer and coating; this boundary is clearly visible at the glass composite microstructure [11].

Scheme of formation of the glass composite spraying is as follows.

As well as in the first case, to reduce the thermal shock and to provide the better adhesion with the coating, the underlayer was preheated to the temperature 350-400 $^0$C. The coating was shaped as a rod. The composition of the coating consisted of glass waste and liquid glass. The sputtering was done at the distance of 50-80 mm from the plasma torch edge. Due to dynamic pressure of the plasma jet the particles of the coating are fused into the underlayer surface. Due to the high temperature on the particles surface they interfuse not only with the underlayer, but with each other as well. Besides, due to the high temperature the viscosity and surface tension of the coating are reduced, which promotes the healing of surface defects. So, the surface of the coating is healed, the cracks are closed and the contact of underlayer with the atmosphere is reduced. In this period the contact layer is formed, though it doesn't have such pronounced boundaries, as in the first case. The surface is of relief character [12].

In both cases at the phase boundary (i.e. in the contact layer) there are formed crystalline phases, which provide the adhesion strength between coating and underlayer. The process of contact layer formation goes on within 30-50 s. Within this period the glass composite surface is completely healed with the fused coating layer. The next stage is the slow cooling of the product.

So, we have established, that the adhesion of coating with the underlayer at plasma-chemical treatment goes on due to the contact layer, which is formed as a result of crystalline phases formation of, presumably, potassium, sodium and calcium aluminosilicates ($KAlSiO_4$, Na $AlSiO_4$, $CaO{\cdot}Al_2O_3{\cdot}6\,SiO_2$).

As it was mentioned before, the main role in forming the heat-insulating glass composite is played by diffusion processes between the coating and underlayer, i.e. at the plasma-chemical treating of the foam glass surface there also takes place the partial healing of surface due to the melting of interpore partitions and the surface layers are crystallized [13].

**Conclusion**

There has been obtained a new class of high-performance heat-insulating glass composite with protective-decorative coating on its face surface, not requiring any additional protective plaster coatings or facing materials. The main aesthetic, consumer-oriented and performance characteristics of the obtained material are presented in table 1.

**Tabl 1. Performance characteristics of the designed material**

| # п/п | Property | Value | |
|---|---|---|---|
| | | Glass composite | Uncoated foam glass |
| 1 | Acid-resistance | class AA | resistant |
| 2 | Water-resistance of the coating | III hydrolytic class | – |
| 3 | Compressive strength, MPa | 6,03 | 2,23 |
| 4 | Flexing strength, MPa | 2,16 | 0,83 |
| 5 | Freeze-thaw resistance, cycles | > 50 | > 50 |
| 6 | Heat conductivity, W/m·K | 0,07 | 0,07 |
| 7 | Density, kg/m$^3$ | 176 | to 170 |
| 8 | Water sorption, % | <5 | <5 |

**Conclusion**

So, taking into account the factors, which influence the intensification of pore-formation process and structure formation of high-porosity heat-insulating materials, at combining the developed plasma-chemical methods of decorating the foam glass surface, allow improving the water-resistance, durability, strength, decorative properties and architectural merits of modern buildings and constructions. With regard to these features of the suggested heat-insulating composite on the base of foam glass with protective-decorative coating on its face surface, we may state that the glass composite is the most promising heat-insulating material for application in building and other spheres of engineering.

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