Engineering exterior translucent coatings with the use of profile glass and composite materials

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Abstract. The paper raises certain questions concerning the use of structural glass (glazing) in external vertical enclosures of modern construction systems, pointing to the need for combining composite materials, especially composite foam, in translucent enclosures, which helps dramatically reduce the weight of external panels while improving their heat and sound insulation performance. It also emphasizes the relevance of energy efficiency at the building operation and building construction stages, as energy efficiency is not only the heat saving performance during building operation, but also a high effectiveness of the construction technology.

The novelty of the study lies in engineering a wall panel possibly combining two materials — profiled glass and composite foam. The paper not only details the panel design, but also describes the manufacturing technology and the envelope arranging processes with two wall panel attachment methods and related joint assemblies. Based on a number of scientific publications, the handling mechanisms are discussed suitable for different ways of coupling the structural elements — wall panel and floor slab. Focusing on box-type structural glazing, the authors stress the need for further study involving other types of structural glass (channel shaped, ribbed, trimmed) to create multicomponent wall panels for a variety of regional climate conditions.

Introduction

As shown by the analysis of the scientific publications [1-20], the popularity of translucent external coverings is explained not only by their aesthetic side, or their suitability for creating unique architectural forms as part of the today’s globalization context, but also by the energy efficiency of relevant buildings and facilities. At the same time, the use of structural glass for creating energy efficient structural elements appears understudied as compared to other translucent materials. Energy efficiency is understood by the authors not only as the ability to save heat at the building operation stage, but also as a high effectiveness of the construction technology at the building construction stage. This, in turn, implies the use of easy-to-install enclosing wall panels requiring minor workforce and machinery operating time expenditure for their installation. That said, the current practice of making construction systems demonstrates translucent self-supporting envelopes made of structural glass that are configured as solid external enclosures nearly along the height of a story and sometimes along the entire height of a building, which is inconsistent with the modern standards featuring light-weight facades.
On the other hand, the construction practice shows that glass and reinforced concrete panels as well as fiber-reinforced foam concrete panels with waste glass addition have been successfully used in the construction of low-rise as well as high-rise and unique buildings and facilities for more than twenty years [21-23], thus helping to resolve a number of construction industry issues associated with energy efficiency, environmental friendliness and enhanced constructability.

This paper will consider the possible applications of structural glass and composite materials, in particular, composite foam and fiber-reinforced foam concrete, for making energy efficient wall panels designed for use as part of external vertical enclosures in modern construction systems.

**Wall panel design**

For making this panel, several composite reinforcing bars are placed through the body (internal cavity) of a box-shaped unit of structural glazing. The protruding ends of the bars on both sides will eventually be attached to a composite foam (or fiber-reinforced foam concrete) structure. In order to prevent composite foam (fiber-reinforced foam concrete) from penetrating into the cavity of the structural glazing, this cavity is closed with U-shaped plugs from both ends (refer with Figure 1).

*Figure 1.* Design of the newly developed panel made of structural glass and composite materials: (1)—composite foam (or fiber-reinforced concrete); (2)—composite reinforcement; (3)—plug location; (4)—box-shaped structural glazing

On the outer side, the plugs have a corrugated (rough) surface, which provides better cohesion of the composite foam (fiber-reinforced foam concrete) layer with the U-shaped plug. The number and diameter of composite reinforcing bars, as well as the size of the plugs and the two-side concrete parts of the panel are calculated assuming the width and length of the panel and also its functional reliability.

The use of composite foam in such panels serves two purposes. First, composite foam is not only a construction material, but also an excellent thermal insulant [24-26]; second, the light weight of composite foam (as compared to concrete) allows making lightweight panels to ensure an enhanced effectives of the installation technology.

In case of structural glass, the use of products with different color palette makes it possible to build facade systems in a variety of color schemes, both within a single story (refer with Figure 2) and across a building or facility as a whole.
Figure 2. Optional appearance of a facade fragment with the newly developed translucent panels made of structural glass and composite materials: (1)—panel part made of a composite material; (2)—panel part made of structural glass; (3)—reinforced concrete column; (4)—facade cassette

Development of technological solutions for making translucent facade panels of structural glass and composite materials

The organizational and technological solutions for arranging the suggested translucent facade panels depend on the functional purpose, number of stories, structural layout and other characteristics of a building or facility.

The facade panels, as installed, can be secured to cast-in-situ floor slabs using bolted connections and aluminum L-shaped coupling profiles. In this case, the coupling members can be either visible from the outer side of the facade or vice versa (refer with Figure 3).

Figure 3. Connection diagram for structural glass facade panels and floor slabs: (a) — with externally visible connecting aluminum profiles; (b) — with invisible connecting aluminum profiles: (1)—floor slab; (2)—wall panel; (3)—connecting G-profiles; (4)—bolted connection; (5)—facade cassette

A secure attachment of these elements inside the body of a floor slab during its manufacturing (after installing the reinforcing cages) can be ensured by strategically placing plastic pipe fittings filled with felt (or a similar material) so as to prevent the ingress of concrete mixture in the respective areas. The height of the pipe fitting must be slightly greater than the thickness of the floor slab, and the diameter shall be the same as the bolt diameter calculated for the bolted connection.

To make the facade system looking more aesthetic, a facade cassette of appropriate height can be used in the first case. A facade cassette is placed on the outer side of the facade system at the level of
the visible profiles, bolts and the end side of the floor slab. Similarly, façade cassettes can be used for lining reinforced concrete columns (refer with Figure 1). They are mounted simultaneously with façade cleaning from the working platforms of lifting mechanisms, always in strict compliance with the occupational health and safety regulations.

The wall panels erection technology includes the following processes:

1. Plotting the points of attaching the aluminum L-shaped coupling members (angle blocks) on the floor slab (at the floor or ceiling level), i.e. removal of pipe fitting ends protruding beyond the slab contour with the help of cutting tools.
2. Removing felt from the internal space of the pipe fittings.
3. Attaching the aluminum L-shaped coupling members (angle blocks) to the floor slab.
4. Installing a wall panel with a temporary bolted connection through the aluminum L-shaped coupling members.
5. Checking the vertical and horizontal alignment of the panels with geodetic tools.
6. Anchoring the wall panels in place.
7. Sealing butt joints between the panels at the floor or ceiling level with polyurethane sealants.
8. Sealing butt joints between the panels with silicone pastes.
9. Installing façade cassettes to cover the coupling profiles and bolts (depending on the panel installation technology).
10. Cleaning the facade.

The supply and installation of wall panels can be arranged using the methodology described in detail in the study [27], i.e. with mini-crane placed on the floor slabs of a frame high-rise building or skyscraper. For low-rise and mid-rise buildings, self-propelled cranes can be used given their suitable capacity and hook lifting height. It is also worth noting that the technology described in the paper [27] is most suitable for high-rise frame buildings with load-bearing columns invisible from the façade side.

An alternative to this technology can be the technology suggested for installation of external wall panels where the modern lifting machinery – reach trucks – is used as detailed in the paper [28]. This technology consists in arranging remote construction platforms at the level of the floor slab of the story where the external wall panels are to be installed. The reach truck body, which remains inside the contour of the building (on the floor slab), extends a mast with a fork to receive a pack of external wall panels handled by a crane so that the mast when moved forward could reach the remote construction platform. The mast with attached wall panels is placed vertically at the time when the enclosing structures are supplied. Then the mast is tilted so that it could not only pass through the gap between two floor slabs, but also safely transport the wall panels. During transportation, the panels are additionally secured so as to exclude the risk of their tipping over. Once the wall panels are delivered to the place of installation, the mast takes up the position required for their installation, the panels are released by way of removing additional securing elements and installed in place. If several remote construction platforms are placed on various stories, the installation process can be arranged as a flow line. The technology suggested is not fundamentally new, as it was used earlier in the construction of high-rise buildings as discussed in the paper [29], where self-propelled trolleys were used instead of reach trucks. However, modern reach trucks have certain advantages as compared to self-propelled trolleys, such as: mobility, maneuverability, lifting height and other capabilities allowing for the performance of various construction operations inside a story of a building [28]. Still, the installation of the suggested wall panels using reach trucks is only possible with the use of the coupling layout shown in figure 3, a. Otherwise, a number of traditional technologies can be used to accomplish this task.

**Experimental research**
For the experimental part, a model panel with reduced dimensions was manufactured under the laboratory conditions according to the above described technology. The non-transparent part of the panel was made of fiber-reinforced foam concrete due to the absence of composite foam. The purpose
of the experimental part was to check the strength performance of a wall panel at the junction of two materials. Out of the ten sample wall panels, only three failed to meet the strength requirements. Considering the results of the experiment, a conclusion was made that a reliable connection between panels within the non-transparent part can be achieved using a plug-and-socket connection.

Summary
The new panel consisting of box-shaped structural glazing combined with composite materials can be categorized as an energy efficient product, because the composite materials (composite foam and fiber-reinforced foam concrete) recommended for its manufacturing are not only construction materials, but also excellent thermal insulants. Also, the box-type structural glazing as such is a superb sound and heat insulating translucent material [30]. The use of the recommended composite materials, when combined with structural glass, allows creating light-weight products, which are very well suitable for installation purposes. The light weight of the panels is achieved due to a low bulk density of composite foam. When considered as a construction material, composite foam was found to be five times lighter than structural glass. Besides, being fire-resistant, it helps improve the fire safety of construction systems.

Therefore, the novelty of this paper lies in the opportunity for making light-weight and easy-to-install translucent external wall panels consisting of box-shaped structural glazing combined with the composite materials under consideration. The use of these panels helps reduce heat losses through enclosures, because structural glass can be partially replaced with an excellent heat insulating and construction material — composite foam. Although this paper only considers box-type structural glazing with two joints, panels suitable for southern regions can be develop using other types of profiled glass (channel shaped, ribbed, trimmed), which will require further studies on this topic. Nevertheless, the theoretical and practical results obtained at this stage of the study allow understanding the practical value of the study consisting in the development of the new technological solutions for making vertical translucent enclosures with the use of multicomponent light-weight and easy-to-build products.

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