Development of new tool joint for modular systems made of cellular polycarbonate

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Abstract. The paper discusses the use of solid and structural polycarbonate modular systems in energy efficient facades and roofs of unique modern buildings. Inferior to nearly all translucent materials by light transmission, cellular polycarbonate sheets offer a combination of important consumer properties, such as impact resistance, light weight, flexibility and chemical stability. At the current stage of construction development featuring cellular polycarbonate modules, the assembly (installation) fails to meet the constructability and work safety requirements. To address these drawbacks of cellular polycarbonate structural modules, a new butt joint is suggested consisting of two separate C and T shaped profiles, where one joint profile is placed inside the other one's cavity after their fastening to a cellular polycarbonate sheet. To build a variety of most complex curved enclosures, the coupling parts can be rounded similar to existing ready-to-use cellular polycarbonate sheets with U-joints. The paper outlines the installation of cellular polycarbonate modules with the new joint profiles. To improve the constructability of vertical translucent enclosures, modular systems can be enlarged on special benches and installed using vacuum lifting beams. The reliability and safety of the new structures is ensured by extensive profile resting upon metal or other load bearing supports.

1. Introduction
Polycarbonate is broadly used for building translucent structures as part of unique construction projects, and the recent tendency of embodying complex elements and shapes using polycarbonate is becoming increasingly evident, especially in the construction of stadiums, sports complexes, and Olympic facilities. In terms of light transmission, cellular polycarbonate is known to be inferior to nearly all translucent materials except for polyester. However, the unique nature of polycarbonate creates a paradoxal mix of other important consumer properties: high impact resistance, light weight, flexibility and chemical stability [1-3]. Considering the vast opportunities for using polycarbonate, there is ongoing search for new ways to strengthen polycarbonate based modular structures [4], including the ways employing additive technologies [5]. The transformations of the appearance of construction systems achieved through the use of polycarbonate structural elements within a variety of color schemes, aided by the use of mirror surfaces or LED backlighting, also allows reducing heating and lighting costs as well as operating costs. These are the specific features that have driven light metallic structures and modules, as a means for building outer coating for the construction systems in question, from the construction market. The light transmission factor of cellular polycarbonate varies depending on the color palette of sheets [6, 7]. This factor is adversely affected by additional layers of coating containing TiO₂, which is primarily intended to improve the self-cleaning ability of sheets by removing dirt and...
dust [8]. Despite a liner dependence of light transmission on the thickness of the coating layer (the greater the coating thickness, the lower the light transmission factor), the authors of the paper [8] note that the use of additional coating helps improve the hardness of modular systems made of solid and cellular polycarbonate and their resistance to scratching.

At the same time, it is worth mentioning that the construction of energy efficient buildings and facilities based on making-up translucent enclosing structural elements [9-29] appears to be the dominant tendency at the current stage of development of construction technologies. This is why modular systems made of polycarbonate are often combined with other energy efficient translucent coatings.

The common observation that modules made of polycarbonate sheets are easy to install is true for solid polycarbonate, and as such, the scientific paper [30, 31] proves to be of special interest in this area. Here, it is important to note that at the current stage of construction development featuring cellular polycarbonate modules the assembly (installation) techniques fail to meet the current constructability and work safety requirements.

2. Mein text

2.1. Goal, tasks, research methods

The setting of the goal and objectives of this research is associated with the study of the existing types of joint profiles and the development of a new joint profile meeting the constructability requirements. The first stage of the study was focused on the existing joint profiles offered by the world's leaders in the production of cellular polycarbonate (CPC): Polygal, Sabic, Bayer, Palram, Gallina and others. At the second stage, the benefits and drawbacks of such joint profiles were identified in respect of their assembly and attachment to bearing surfaces. The analysis of publications and electronic media data shows that flexible coupling profiles made of polymer plastic demonstrate a number of specific advantages, which simplify the assembly of cellular polycarbonate modules when building facades or roofs and help extend the lifetime of these structures.

In general, the key research methods included the analysis, generalization and comparison of profiles and assembly techniques for cellular polycarbonate modules, as well as analogy determination.

2.2. Brief description of joint profile and installation techniques

Traditionally, a modular CPC system consists of structured (cellular) polycarbonate sheets coupled by an integrated joint with a thickness of 6 to 20 mm (occasionally reaching 32 mm), a customized extruded polycarbonate profile (with a lock on one side), plugs, fasteners and expansion joints. This structure is set to efficiently absorb thermal expansion and even capable of controlling it. The regular system package includes customized elements channeling thermal expansion and contraction in the directions which are the least dangerous for the structure as a whole.

The suggested coupling profiles (T and C shaped profiles), as shown in figure 1 and figure 2, form a uniform polycarbonate coating. The dimensions of the coupling profiles given in the figures correspond to a specific type-size configuration of cellular polycarbonate sheets only. Generally, they can be designed to suit any geometric dimensions of CPC sheets to be coupled.

![Figure 1. External view of a C-profile](image-url)
The profiles are installed on the side ends of panels with an overlap (one inside the other). This type of attachment provides a quick and robust coupling of panel. The profiles are light weight, flexible and simple for installation. The length of the profiles corresponds to the width of CPC sheets.

The profiles provide a sound and airtight connection of panels and their attachment to load-bearing supports of the frame, while allowing for expansion (contraction) depending on the seasonal variation of the ambient temperature.

When preparing polycarbonate panels for installation, the end sides of the material are required to be covered with an aluminum tape according to the traditional methods. As is known, there are two types of tapes: perforated aluminum tape to protect the sheet ends directed downwards, and sealing aluminum tape to protect the upper sheet ends from the effects of moisture and dust. The profiles are then attached to the panel ends: for both C-profiles and T-profiles, figure 3, the end profile structure is intended to ensure tight fitting to the sheets, and hence, does not require gluing or any other additional fastening. After that, the panels are laid with the T-profile fitting into the C-profile, as shown in figure 4, i.e. the T-profile is inserted in the cavity of the C-profile.

The lower edge of the panel is fastened by the lock on the lower side of the C-profile shown in figure 4 and can be additionally secured with sealed self-tapping screws through the resulting modular tool joint. The upper edge of the panel remains unsecured in order to handle lengthwise thermal expansion of the panels. The profiles provide a sound and airtight connection of panels and their attachment to the load-bearing supports of the frame, while allowing for expansion (contraction) depending on the seasonal variation of the ambient temperature.
The transportation of the profiles to the construction site always requires their appropriate packing. To build vertical enclosures covering large areas, consolidated CPC modules can be assembled on the integration bench for further attachment to bearing surfaces and, once delivered in special packing to the construction site, can be immediately installed using vacuum lifting beams. All protective films are required to be removed after installing all structures. By rounding the coupling areas, C and T shaped profiles, similarly to ready-to-use CPC sheets with U-joints shown in figure 5, can be configured to fit the most complex curved enclosures.

![Figure 5. Fragment of CPC sheets with a U-joint](image)

Thanks to their flexibility, these profiles can be used for making curved structural elements for both vertical and horizontal inclined envelope structures.

3. Conclusions
The development and search for innovative ideas, as well as their adaption for construction of unique facilities with translucent enclosures made of CPC sheets has become one of the key focus areas worldwide in resolving the issues of energy efficient building construction. However, the current variety of butt joints, whether in form of separate profiles, or as prefabricated sheets with tool joints, including innovative configurations for large-scale plane modular CPC structures, is still insufficient to attain the desirable results, as it fails to fully meet the current constructability and work safety requirements.

The joint profiles developed by the authors allow coupling CPC sheets with minor workforce and time resources, as justified by the simulation of a specific building using the BIM technologies. Also, an array of curved structures can be created by varying the form of coupling surfaces and the flexibility of profile. The extensive resting of the profiles upon bearing surfaces of metallic or other supports makes it possible to build operationally reliable translucent enclosures. Because this development is purely theoretical on its current stage, the practical implementation will involve additional experiments in line with the engineering designs and constructability analyses. The practical relevance of this study consists in applying these materials to improve the technology of making translucent coatings featuring CPC modules.

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