Architectural and decorative concrete with photoluminescent pigment

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Abstract. The authors received glowing products from architectural and decorative concrete with the use of photoluminescent pigment, formed in various positions and any configuration that does not lose their architectural expressiveness over a long period of operation. The use of products with a glow effect provides increased safety at night and is an additional means of signaling on dangerous and worst-lit sections of roads, parking lots, bicycle paths. Optimally selected materials and the method of surface treatment of products provide decorativeness of small architectural forms in the daytime. The compositions of architectural and decorative concrete were designed and the influence of the quantitative content of photoluminescent pigment on the main physico-mechanical characteristics was evaluated. The rheological properties of cement suspensions and architectural and decorative concrete based on them are studied, and the decorativeness and luminescence of products with photoluminescent pigment are evaluated according to the methods developed by the authors. The resulting recommended composition of glowing architectural and decorative concrete with using white Portland cement (CEM I 52.5 N), fractionated marble crushing waste 0.2-0.5; 0.5-1.0; 1.5-2.0; 3.0-7.0; 5.0-10.0; 10.0-20.0, modifier of polycarboxylate type and photoluminescent pigment, allows to obtain the products with a glow effect, high architectural, decorative and physico-mechanical characteristics that correspond to the operating conditions.

1. Introduction
The problems of production and application of architectural and decorative concrete and products based on it are generally studied in Russian and international literature. Depending on the use, pigments and modifiers can be add to the composition of decorative concrete in order to obtain products with high esthetic and operational properties [1-4]. In the technology of manufacturing products from decorative concrete of complex configuration, the mixture must be sufficient workability, minimal compression and thermal expansion [5]. The aggressive urban environment conditions influence small architectural forms, so products made of decorative concrete must have high physic-mechanical characteristics. The esthetic importance of such products lies in the architectural expressiveness of the surface structure. The small architectural forms with these properties easily integrate into any architecture and design environment. However, the question of
The functional use of decorative concrete products in the night has not been studied before by the authors. The introduction of photoluminescent pigment into the composition of decorative concrete, while maintaining all the necessary operation characteristics, will provide an additional property—glow for the architectural expressiveness of products at night.

This subject is important because the glow effect allows you to expand the possibilities of functional application of architectural and decorative products and increase their technical and economic efficiency, by saving electricity by excluding additional lighting sources in some areas, as well as improving the safety of road traffic and pedestrians.

Currently the use of photoluminescent pigment in concrete is not well studied. The well-known method of introducing photoluminescent pigments into products made of decorative concrete, aimed at providing glow only of the top decorative layer, has a number of important disadvantages: it does not provide the glow for the full working life does not technologically allow manufacturing products of complex configurations and, most importantly, reduces the physico-mechanical characteristics [6].

The purpose of the research is to determine the composition of decorative concrete with photoluminescent pigment with the possibility of manufacturing products with a front surface formed in different positions and different configurations; to ensure high architectural and decorative expressiveness in the daytime and stable glow at night during the entire working life without additional coating and without reducing the physico-mechanical characteristics of concrete [7,8].

To achieve this purpose, the criteria for choosing Portland cement were determined; the rheological properties of cement suspensions with different polycarboxylate modifiers was studied; optimal granulometric compositions of aggregates were developed; the influence of photoluminescent pigment on the rheological and physico-mechanical properties of architectural and decorative concretes was studied.

2. Methods
Physico-mechanical properties of components, rheological characteristics of cement suspensions and architectural and decorative concrete mixes, physico-mechanical properties of products made on their basis were evaluated in conformance with the normative documents [9-11] and the author's methodology for evaluating the luminescence of photoluminescent pigment in concrete.

The glow of photoluminescent pigment in concrete was determined by measuring the luminance with a luxmeter in a dark room (lighting brightness is 0 lx) after the sample accumulated light energy at the chosen lighting source.

The authors evaluated the architectural expressiveness of decorative concrete products using a point system, taking into account each decorative parameter [12].

3. Results and discussion
Decorative concrete is made from the use of white and colored Portland cement, special aggregates, pigments, modifiers that allow to get colored concrete, as well as concrete with a texture close to natural stone materials. Decorative concrete with the use of photoluminescent pigment accumulates energy, converts it into light at night, and retains the brightness of the glow for a long period of time [13, 14]. At the first stage, the authors conducted an experiment to determine the glow of photoluminescent pigment in concretes made of white and gray Portland cement. The criteria for choosing Portland cement are decorative and glow effect of concrete samples using different cements.

For carrying out an experiment to accumulate light energy, we introduced a photoluminescent pigment for 5% weight of the cement into a concrete mix using white and gray cement. After polishing the surface layer, the samples accumulated solar energy in natural light for 30 minutes. The glow of the sample with white Portland cement is 1.5 lx, the sample on gray Portland cement does not glow (Figure 1).
During the experiment, the authors found that the type of Portland cement affects the glow of the finished product. Grey Portland cement mutes the effect of the glow – so it is very difficult to achieve the brightness of the glow when introducing the pigment, the same as when using white Portland cement with the same dosage of photoluminescent pigment. For the production of concrete with a glow effect, white Portland cement is used [15].

We evaluated the decorative properties of concrete samples by three main parameters: color, texture and structure, which include the appearance of the aggregate structure on the surface of decorative concrete, the degree of development of the figure, the degree of manifestation of the structure, glow, surface texture, etc. The sample consisting of white Portland cement and marble stone crushing waste was highly evaluated, and it is highly decorative concrete [16, 17].

Glowing products made of architectural and decorative concrete contain pigments in the range of up to 10 % of the weight of Portland cement, which can greatly affect both the rheological characteristics of concrete mixes and the physical-mechanical characteristics of the products themselves.

At the next stage, the authors analyzed the rheological properties of cement suspensions of white Portland cements with a photoluminescent pigment for 5 % by weight of the binder, modified with polycarboxylate type additives. The results of many experiments of polycarboxylate type modifiers prove their high efficiency for different concretes [18]. The literature review [19-22] showed that the greatest rheological effect with the maximum economic effect is achieved when a modifier is introduced in the range from 0.3 % to 0.7 %.

In our research, we used white Portland cement Aalborg CEM I 52.5 N; white Portland cement Adana CEM I 52.5 R, white Portland cement Holcim DecoCem CEM I 52.5 N. Cement suspensions are prepared with the same water/cement ratio (W/C) and a modifier in the amount of 0.4 % of the binder weight.

The data in table 1 show high starting flowability of cement suspensions made with polycarboxylate type modifiers such as MC-PowerFlow 7951 and MC-PowerFlow 3100. The type of modifier MC-PowerFlow 7951 is more adsorbed on cement grains, providing better plasticity, as a result, the flowability of cement suspension with the use of white Portland cement Aalborg CEM I 52.5 N is higher and is 154 mm compared to MC-PowerFlow 3100, where the cone spread is 70 mm. The Polyplast PC S and MC-PowerFlow 6955 modifiers show lower plasticizing properties in the reduced cement suspensions, in addition, they lose their effectiveness during an hour.
Table 1. Rheological properties of cement suspension with pigment depending on the type of polycarboxylate modifier.

| Type of polycarboxylate modifier | Amount of modifiers, % by weight of Portland cement | The diameter of the flowability of mini cone, D, mm | The diameter of the flowability of mini cone after 1 hour, D, mm |
|----------------------------------|-----------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| White Portland cement Aalborg CEM I 52.5 N |                                |                                                  |                                                  |
| MC-PowerFlow 6955                | -                              | 37                                              | 37                                              |
| MC-PowerFlow 7951                | 0.4                            | 139                                             | 61                                              |
| MC-PowerFlow 3100                |                                | 195                                             | 154                                             |
| The Polyplast PC S               |                                | 153                                             | 70                                              |
| White Portland cement Adana CEM I 52.5 R |                                |                                                  |                                                  |
| MC-PowerFlow 6955                | -                              | 33                                              | 32                                              |
| MC-PowerFlow 7951                | 0.4                            | 95                                              | 41                                              |
| MC-PowerFlow 3100                |                                | 138                                             | 110                                             |
| The Polyplast PC S               |                                | 129                                             | 65                                              |
| White Portland cement Holcim DecoCem CEM I 52.5 N |                                |                                                  |                                                  |
| MC-PowerFlow 6955                | -                              | 31                                              | 29                                              |
| MC-PowerFlow 7951                | 0.4                            | 85                                              | 49                                              |
| MC-PowerFlow 3100                |                                | 120                                             | 79                                              |
| The Polyplast PC S               |                                | 70                                              | 61                                              |

The results obtained by the authors (Table 1) show that the introduction of the polycarboxylate type modifier MC-PowerFlow 7951 into the mix in an amount of 0.4 % by weight of the white Portland cement Aalborg CEM I 52.5 N is the most effective. In addition, we have investigated the water-reducing effect of cement suspensions with different Portland cements (Figure 2). To determine the water-reducing effect, we studied the flowability of cement suspensions depending on the type of polycarboxylate modifier [23,24]. A formula that allows you to calculate the water-reducing effect (1):

\[
W_{re} = \frac{(W/C)_{un}}{(W/C)_M}
\]

\((W/C)_{un}\) and \((W/C)_M\) – water/cement ratio of unmodified and modified cement suspensions with the same consistency.
Analysis of water reduction values (Figure 2) shows that the maximum water-reducing effect ($W_{\text{EF}}$) for white Portland cements is provided by a polycarboxylate type modifier MC-PowerFlow 7951, $W_{\text{EF}} = 1.6-1.73$. This justifies the use of this type of modifier, while the maximum rheological parameters of both modified and unmodified cement suspensions were noted with the use of white Portland cement Aalborg CEM I 52.5 N.

The authors consider the possibility of replacing natural materials with decorative concrete, using stone processing waste as aggregates, which meets current requirements for ecologically clean energy- and resource-saving technologies. Research shows [25-29] that the use of marble in the production of concrete is cost-effective and reduces the damage caused to the environment by this industry. In addition, it is also advisable from the position of increasing the decorative effect of luminous architectural and decorative concrete.

An effective method for determining the optimal ratio of aggregates of different fractional composition and approximating the granulometric composition of the mix to the reference distribution curve is the method of adding up the empirical distributions of the particles of the initial components with the possibility of changing their volume (or mass) fractions in the mix. To determine the optimal granulometric composition, the main criterion is the difference between the calculated granulometric composition of the mix and the sample granulometric composition expressed by the optimal distribution curve (Figure 3).
Based on our research, we have designed a composition of architectural and decorative concrete characterized by compressive strength class C 35/45 and frost-resistance F₁ 200. In the composition of concrete as a binder, white Portland cement CEM I 52.5 N and fractionated waste from crushing marble as aggregates, which allows to obtain products that imitate natural marble as much as possible in their structure (Table 2).

Table 2. Recommended composition of architectural and decorative concrete.

| Constituent materials                        | Materials weight, kg/m³ |
|----------------------------------------------|--------------------------|
| White Portland cement CEM I 52.5 N           | 400                      |
| Marble fractions 0.2-0.5 mm                  | 224                      |
| Marble fractions 0.5-1.0 mm                  | 167                      |
| Marble fractions 1.5-2.0 mm                  | 167                      |
| Marble fractions 3.0-7.0 mm                  | 391                      |
| Marble fractions 5.0-10.0 mm                 | 723                      |
| Marble fractions 10.0-20.0 mm                | 215                      |
| Polycarboxylate type modifier MC-PowerFlow 7951 | 1.6                      |

To determine the influence of the quantitative content of photoluminescent pigment in the composition of decorative concrete on the main physico-mechanical characteristics of products, samples of concrete of the recommended composition were made, shown in Table 3, with a set workability.

Results of testing of compositions numbered 2 and 3 (Table 3), demonstrate that when the content of photoluminescent pigment is up to 10 % of the weight of Portland cement and W/C ≤ 0.45, the compressive strength and frost resistance of samples of lighted architectural and decorative concrete match to the characteristics of concrete without pigment. This confirms the possibility of manufacturing products that have a glow effect and have physical and mechanical characteristics that match to the operating conditions.

Table 3. Test results of the control composition and compositions of decorative concrete with different dosage of photoluminescent pigment.

| Composition | Amount of photoluminescent pigment, % by weight of Portland cement | W/C  | Averaged density, kg/m³ | Compressive strength, MPa at the age of, days | Frost resistance |
|-------------|---------------------------------------------------------------------|------|-------------------------|---------------------------------------------|------------------|
|             |                                                                     |      |                         | 7                                           | 28               |
| 1           | 0                                                                   | 0.42 | 2363                    | 41.5                                        | 55.3             | F₁ 200          |
| 2           | 5                                                                   | 0.40 | 2363                    | 40.4                                        | 55.0             | F₁ 200          |
| 3           | 10                                                                  | 0.45 | 2360                    | 39.8                                        | 54.9             | F₁ 200          |
| 4           | 15                                                                  | 0.45 | 2350                    | 20.5                                        | 32.3             | F₁ 100          |
| 5           | 20                                                                  | 0.44 | 2364                    | 18.4                                        | 28.5             | F₁ 100          |

During the formation of decorative concrete products with the use of photoluminescent pigment in production conditions, it is important to ensure high-quality mixing of components, the introduction of photoluminescent pigment into the mix at the dry mixing stage in the range of up to 10 % of the weight of Portland cement, the necessary use of a modifier and W/C ≤ 0.45. It is recommended that the fresh-formed product is covered with a waterproof material and kept for at least 24 hours in the form and another 96 hours after removal from the form without influence of atmospheric factors.

For the purpose to get better decorative characteristics, as well as to fully use the potential of the photoluminescent pigment in the product, the front surface is polished to expose the aggregate and...
show the marble structure. It is recommended to cover the polished surface with an acrylic-based penetration, which increases the decorative expressiveness of the structure and provides a long-term protective effect of the surface.

4. Conclusions
The use of concrete in the modern construction industry is determined not only by its technological, operational and economic characteristics, but also by its architectural and decorative expressiveness and ecological expediency.

1. For the production of decorative concrete with a glow effect, it is necessary to use white Portland cement, photoluminescent pigment up to 10 % of the weight of Portland cement and observe the W/C ≤ 0.45.
2. Authors confirmed the possibility of using marble stone crushing waste as aggregates in decorative concretes, but with the condition that the granulometric composition of the mixture approximates the reference curve for the distribution of components.
3. The composition of architectural and decorative concrete designed by the authors with the use of white Portland cement (CEM I 52.5 N), fractionated marble crushing waste, polycarboxylate modifier and photoluminescent pigment allows to obtain products characterized by high physico-mechanical and architectural and decorative characteristics with the effect of glow, meeting modern environmental requirements and expanding the range of functional applications in modern construction.

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