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Abstract

Defined-Performance Concretes Using Nanomaterials and Nanotechnologies †

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The industry of building materials and construction, despite its obviously conservative character, quite often has to face the so-called "industrial revolution of the XXI century". New trends and new methods of experimentation and research are becoming the foundation for perspectives on the creation of high-tech products and processes characterized by a guaranteed reliability index, developing the principles for manufacturing up-to-date "supermaterials", and are marking the start of the sixth technological wave.

A special place among high-tech products is occupied by defined-performance concrete. An impressive breakthrough in construction technologies in the 21st century was achieved due to the properties of modern concrete, which have recently seemed unattainable. These include extremely low values of the water/cement ratio and air content of the concrete mixture, with long-lasting flowability, cohesion and uniformity; the ability for fresh concrete to easily and completely fill in a formwork of any configuration, with dense reinforcement, and without the use of energy for horizontal or vertical mix pouring; the ability for concrete to achieve a given strength, with the development of adjustable strength depending on the climatic factors; and a dense concrete structure at the nano-, micro- and macrolevel to ensure high strength, resistance and durability.

The interdisciplinary nature of concrete science contributes to large volumes of fundamental laws and the provisions of physical and colloid chemistry, chemistry of high-molecular-mass compounds, modeling methods, computer science, etc., being involved in their methodologies. Expanding the boundaries of understanding of its essence is an urgent task in modern concrete science.

All these concepts reflect the formation of a new technological pattern in concrete science and the concrete industry, which means a transition away from the established approaches and stereotypes.

The presence of nanomaterials and nanotechnologies in the construction segment is becoming more prominent. Today, in the total global market of nano-products, the construction industry "consumes" up to 3% of its volume and value in terms of the total market of nanomaterials, and in some segments, such as nanocomposites, up to 11%. The detailed analysis and long-term forecast for the development of research and the application of nanomaterials and nanotechnologies in construction shows that cement and concrete cover over 40% of the nanotechnology products in construction materials (the market value is about USD 5.6 billion), with a predicted annual growth of more than 10%.

In the transition from macro- to nano-range size, significant changes were noticed in electron conductivity, optical absorption, chemical reaction activity and mechanical properties, as well as in surface energy values and surface morphology of the composites.

The development of appropriate methods for determining properties and reaction control in nanostructures can lead to the creation of new materials, technologies and devices.

Recent advances in nano-chemistry and the development of new methods for the synthesis of nanoparticles are now expected to offer a new range of possibilities for the improvement of concrete performance. The incorporation of nanoparticles into conventional construction materials can provide the materials with advanced or smart properties that are of specific interest for high-rise, long-span or intelligent infrastructure systems.

Self-regulating concrete (SRC) is one of the most in-demand subjects in the modern concrete science. The choice of components and the design of SRC compositions are based on a prognostic assessment of the direction of spontaneous processes, to ensure high functionality at any technological or operational stage. The concept of "self-regulation" should be interpreted as the technologically predicted course of spontaneous processes in order to achieve the maximum possible functionality of the interacting components and concrete mixes, which meets the concept of defined-performance concrete (DPC).

Today, the successful implementation of a number of self-regulating concretes with defined performance is well known. Concretes that are self-compacting (self-consolidating), self-cleaning, self-healing, self-stressing and self-expanding, and self-sensing, and other much stronger, more rigid and durable structurally advanced cement materials stand out among them.

Examples of successful applications of SiO_2, TiO_2, Fe_2O_3, Al_2O_3, $CaCO_3$ nanoparticles; nanosized spinel $MgAl_2O_3$; nanoferrit $ZnFe_2O_4$; and nanoclays in concrete are given. The most promising contemporary developments include the synthesis and application of new forms of carbon, viz fullerene (C_{60}, C_{70}, C_{540}), graphene oxide (GO) and new types of carbon nanotubes.

For structural concrete, the most significant example of a wide industrial nanotechnology application is steel and FRC reinforcement with modified nanostructures. These bars have a much longer service life in a corrosive environment, which reduces the construction cost. Among the products, produced from the late 1990s on the basis of nanotechnologies, the most important are different coatings that increase the structural service life and give unique properties to structures.

Humankind is going through the changes in civilization's technical paradigm. Under the conditions of the planet's population growth and the inevitable emergence of raw material and power shortages in construction, quite a rapid displacement of traditional materials and technologies, through energy-saving and material-efficient solutions, must be a determining factor. Nano-binders and nano-engineered cement-based materials with nano-sized cementitious components, or other nano-sized particles, may be the next ground-breaking development.

In the near future, the manifestation of the general principles of nanotechnology for concrete and reinforced-concrete development should be expected in the production of high-quality ultra- and nanodispersed powders with stable chemical, phase and granulometric composition, in the development of new types of reinforcing elements (filamentary crystals, fibers, microspheres and dispersed particles); in the creation of new, defect-free, extremely strong reactive powder concretes, thermo-resistant composition materials with different electric conductivity levels, and nanosystems for health hazards and nuclear power stations; and in the development of the scientific foundations for designing specialized technology equipment with automated systems for cement-composite quality control.

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