Abstract

Defined Performance Concretes using Nanomaterials and Nanotechnologies †

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The industry of building materials and construction, despite of their obviously conservative character, quite often has to face so-called "industrial revolution of the XXI century". New trends, new methods of experiments and research are becoming perspective foundation for creation of high-tech products and processes characterized by guaranteed reliability index, developing principles of 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 the 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 water/cement ratio and air content of the concrete mixture with long-lasting flowability, cohesion and uniformity; the fresh concrete ability to easily and completely fill in the formwork to concrete of any configuration with dense reinforcement without the use of energy with horizontal or vertical mix pouring; the concrete ability to achieve a given strength with an adjustable strength development subject to climatic factors; dense concrete structure at the nano-, micro- and macrolevel as a factor ensuring high strength, resistance and durability.

The interdisciplinary nature of concrete science contributes to large volumes of fundamental laws and provisions of physical and colloid chemistry, chemistry of high-molecular mass compounds, modeling methods, computer science, etc. being involved into its methodology. Expanding the boundaries of understanding their essence is an urgent task of 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, on the total global market of nano-products, the construction industry "consumes" up to 3 % of volume and value 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 application of nanomaterials and nanotechnologies in construction shows that the cement and concrete cover over 40 % of the nanotechnology products in construction materials (market value is about $ 5.6 billion) with a predicted annual growth more than 10 %.

In the transition from macro- to nano range size, significant changes were noticed in electron conductivity, optical absorption, chemical reacting activity and mechanical properties, as well as in surface energy values and surface morphology of the composites. The development of appropriate methods of properties and reactions control in nanostructures can lead to creation of new materials, technologies and devices.

Recent advances in nano-chemistry and the development of new methods for synthesis of nanoparticles are now expected to offer a new range of possibilities for improvement of concrete performance. 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 the most in-demand subjects of 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 and 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 designed performance is well-known. Self-compacting (self-consolidating), self-cleaning, self-healing, self-stressing and self-expanding, self-sensing concretes and other much stronger, more rigid and durable structural 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 nanotechnologies application is the steel and FRC reinforcement with modified nanostructures. These bars have a much longer service life in corrosive environment, which reduces the construction cost. Among the products, produced from the late of 1990s on the basis of nanotechnologies, the most important are different coatings that increase the structural service life and give unique properties to structures.

The mankind goes through the change of civilization technical paradigm. In conditions of the planet population growth and inevitable emergence of raw material and power shortage in construction quite rapid displacement of traditional materials and technologies by energy-saving and material-efficient solutions must be a determining factor. Nano-binders and nano-engineered cement-based materials with nano-sized cementitious component or other nano-sized particles may be the next ground-breaking development.

In the near future, manifestation of 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 creation of new, defect free extremely strong reactive powder concretes, thermo-resistant composition materials with different electric conductivity, nanosystems for health hazards and nuclear power stations, and in the development of scientific foundations of designing specialized technology equipment with automated systems of cement composite quality control.