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Improving New Generation Concretes (NGCs) by Introducing Technogenic Materials

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Abstract. Currently, inclusion of technogenic materials as components of new generation concretes (NGC) attracts attention of researchers and engineers from various countries. Wide application of high-strength concretes with increased cement stone content, fineness of binder and aggregate particles, multi-component composition, facilitates improvement in concrete articles quality and further industrialization of the construction production. Due to that, it appears timely to study condition of structural formation of high-strength concrete, a role that technological factors play in this process and its substantial composition. The paper consider some aspects of designing a composition and a production technology for NGC articles, as well as their relevance in modern construction. Results of compositional and technological analysis of high-strength concretes produced with nanostructured modifiers having various chemical and mineral composition and genesis are given. Possibilities are found to reduce binder consumption by introducing technogenic and organic feed; to provide lower consumption of material resources and energy; to employ non-toxic, non-combustible and environmentally-friendly materials.

1. Introduction

Currently, inclusion of technogenic materials as components of new generation concretes (NGC) attracts attention of researchers and engineers from various countries. Wide application of high-strength concretes with increased cement stone content, fineness of binder and aggregate particles, multi-component composition, facilitates improvement in concrete articles quality and further industrialization of the construction production [1-2]. Performance of this type of concrete largely depends on properties of cement matrix and aggregates.

A theoretical foundation for design of new high-quality composite materials is formed by a new science of geonics, which uses results from studies of geological processes and rocks for creation of a new generation of materials [3-5].

2. Materials and methods

Application of new generation of additives, such as carboxylate hyperplastifier MF 1641, French hyperplastifier PREMIA 360 modified with water-soluble products of carbon nanoclusters (Astralenam S) and others regulating concrete's qualitative properties have significant influence on structural formation of powder concrete. Recently, a high-strength powder concrete with a strength of 100-120 on Vickers scale has been produced [6-8]. It is known, that empiric method of research to increase strength of concrete was always long and labor-consuming. Due to that, it is quite current to conduct a preliminary study of structural formation conditions of high-strength concrete, a role of technological approaches in this process and the nature of influence that the structure has on concrete quality.

Some positive results have been obtained for multicomponent concretes: the number of components may reach 7-9 or even more. At that, the most important roles are played by the amount and quality of binder, quality of aggregates and fillers (coarseness, grain size composition, surface quality, cavernosity, strength). At that, the cost of the final material is significant.

An important source of economic improvement of new generation concrete production is to develop structural optimization methods, to facilitate obtaining a high degree of order of its elements, production of binders with technogenic products as raw feed.

The research used mineral additives containing aluminate and carbonate component and typical polymers: Melflux 2651, Melment, C-3, as well as fine-milled quartzitic sandstone, shales and amphibolites from mineral by-products of enterprises in the Kursk Magnetic Anomaly region. Application of complex organo-mineral additives, high-nomenclature binders with technogenic feed as a silica component with superplastifiers and hyperplastifierss is the future of concrete science and concrete production technology.

Despite all the positive characteristics, the cost of high-strength composites and their production technology is rather high and, depending on concrete conditions, may be several times higher than that of normal binders. So, a search for large-tonnage mineral components is important, including those of technogenic genesis; they will allow to increase availability of new high-strength composites without deterioration of their high constructional, technical and aesthetic properties. Complex additives, introduced into the mix as water solutions, powders and emulsions [9-11] have good prospects for high-strength and high quality concretes.

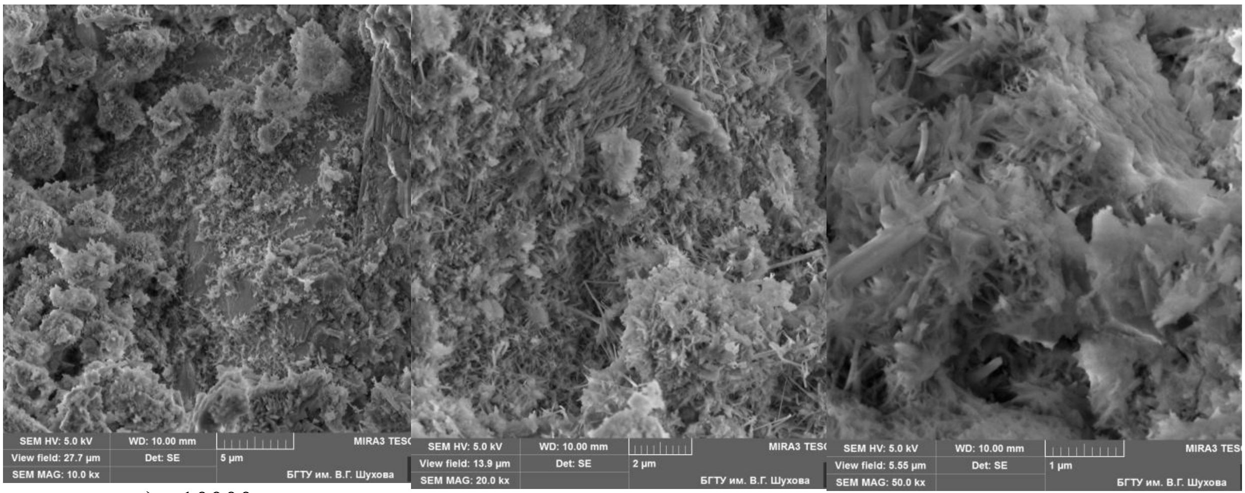
The processes of structural formation in composites with technogenic components demand studies and more active work on optimization of composition and structure of high-strength materials by correct selection of ratios of new technogenic feed products and control over structure formation processes. This will allow to obtain highly functional concretes with low material and energy consumption during their production.

3. Main part

Composite binder, obtained by joint milling with a plasticizing additive has the most uniform dense structure, due to lowering water-to-cement ratio. Also, just like in binder without the plasticizer, there are dense formations observed near aggregate grains, in the contact zones, providing minimal porosity and micro-crack content. This is explained by specific structure of nanostructured modifier (NSM), allowing for active formation of new growth by involving water collected in rock pores, as well as significantly facilitating formation of microstructure in the contact zone and throughout the cement stone.

Introduction of NSM in the cement system allows increasing binder activity up to 75.5 MPa. Increased strength following introduction of the NSM is explained by improved (denser) structure of the cement stone.

Packing and strengthening of structure are determined by growth of crystalline phase and replacement of water contacts between separate phases of new growths with crystalline contacts (Fig.1).



a) ×10000 b) ×20000 c) ×50000

Figure 1. Photomicrography of cement stone produced on the basis of powder concrete with NSM additive

Solid frame in all samples of binders is formed by separate grains of technogenic NSM of various degree of dispersity with vivid chemical contacts at interaction with the new growths. At that, an larger magnification one may see, that these particles are almost completely covered with hydration products, because the technogenic feed particles are a good substrate for formation of seeds for new growths, that is why there is a multitude of globules blended with their surface (Figure 1). Besides that, the smallest aggregate particles, as well as unhydrated cement seeds serve as crystallization centers.

The powder concrete of the optimized composition, obtained by joint milling with a plasticizing additive has a dense and uniform structure (Figure 1). There are dense formations observed near aggregate grains, in the contact zones, providing minimal porosity and micro-cracks content. Specific structure of NSM allowed for active formation of new growth, using the water collected in rock pores, as well as significantly facilitating formation of microstructure in the contact zone and though the cement stone as a whole. This is supported by the results of physical and mechanical testing, showing that the ultimate compressive strength of this binder is two times higher than that of a cement without additives and amounts to 95 MPa.

Microstructures of composite binder obtained by separate milling and further mixing of components is also uniform, but, unlike previous composition, there is a growth of 1nm acicular crystals (Figure 1c) through the whole structure of material. One may see microcracks of 3…5 nm in length, explained by a somewhat worse mechanical activation and diffusion of tuff and binder microparticles. It leads to reduction in ultimate compressive strength by 8.4 MPa compared to binders obtained by joint milling.

Thus, studies of photomicrographs of composite binders obtained by different milling schemes has shown the following. Microstructure of NSM-free cement stone obtained by joint milling is more uniform, the aciculat crystals also grow through the volume of the structure of material (Figure 1) but to a lesser extent. There is a large number of dense new growth near the aggregate seeds.

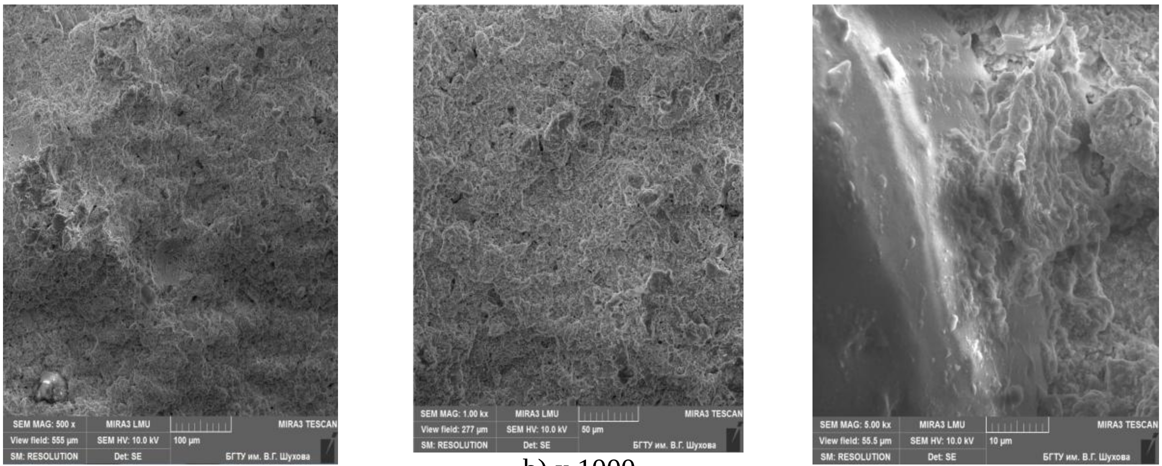
Microsilica, alumina-containing additive and quartz sand (all commonly used nowadays) were selected as silica component. It provided significant improvement in building and technical properties of concrete and construction articles, allowing to reduce weight of buildings and structures without reducing their structural rigidity, stability and lifespan. This target was attained by making the structure denser and reducing the number of pores and microcracks.

The ratio of Melflux 2651 superplastifier was 0.9% of cement consumption. Consumption of cement was reduced by ≈ 18%. A freshly-prepared mix is characterized with increased flow and rheological activity, which allows to apply it in off-form concreting, that is, for production of self-forming articles and structures of large area (cast-in-place floors, playgrounds, etc..).

Table 1. Indicators of building and technical properties of NGC

Property	Value	
	Heavyweight concrete	NGC
Average density, kg/m	2200-2500	2300
Compressive strength, MPa	10-50	97.5
Water-holding capacity, %	78-80	90
Strength-weight ratio (SWR)	0.17	0.36
Watertightness grade, W	2-4	4
Freeze-thaw durability grade, F	50-150	300
Wear capacity, kg/m^2	0.7-0.8	0.36
Contraction	cracks	no cracks
Heat conductance, W/(m*K)	0.8-1.2	1.29

By 28th day of solidification it is characterized with a high degree of highly dense ordered granular component (Figure 2).



a) x 500 b) x 1000 c) x 5000

Figure 2. Microstructure of an NGC on the basis of fine-milled quartzitic sandstone

4. Conclusion

In the figure, one may see the degree of structural condensation of NGC at different magnifications. Almost total absence of pores is evident in the concrete. This is attained by correcting the composition of curing concrete matrix, introduction of optimal amounts of fine technogenic by-products, their closest packing and self-compacting effect of solidification. Increase in structural density was observed throughout the solidification period with increasing effect. It determined production of high-strength concrete with improved physical and mechanical characteristics due to involvement of complex additives. During the curing period, a number of changes appeared in the structure of the formed concrete mixture due to artificial contraction, reduced porosity, absence of some plastic deformations. In the end of the curing period, when the artificial stone reaches its highest density and, as a result, maximum of dynamic characteristics, there is an intense process of calcium hydroxide binding. In liquid phase, final compaction of granular composition is finalized, with reconfiguration of disperse particles.

At the nominal age, high-strength of concrete with complex additive is explained by its ordered granular structure. During the curing period, a number of changes happen in the structure of the formed concrete mixture due to artificial contraction, reduced porosity, absence of some plastic deformations.

Thus, a model of structural formation in modified solidifying composites is proposed, where a principle of structural optimization is applied, involving creation of highly ordered sequence of elements and increased adhesion between the cement stone particles. The obtained results allow to proceed to further improvement of high-quality architectural concrete production. Application of methods of creating model systems of high-strength solidifying composites will allow to obtain new data on structure of material, possibility to improve and control the structure-forming processes.

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