APPLICATION OF NANOTECHNOLOGIES AND NANOMATERIALS IN CONSTRUCTION

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Influence of high-dispersive powder mixture of WC and TiC on the composite materials properties

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ABSTRACT: Introduction. The purpose of the research is to study the effect of a high-dispersive powder mixture of WC, TiC, obtained from recycling of hard-alloy manufactured articles from TK group (titanium-tungsten alloys), on the change in the structural and physical and mechanical properties of cement materials. **Materials and research methods.** WC, TiC Powder (particle size 20–150 nm, agglomerates 300 nm – 1.5 μm) was added to the cement mortar by partial replacement of cement in various concentrations of 0%, 1%, 2%, 3%, 4%, 5% by mass. The basic physical and mechanical properties of the cement paste and obtained cement materials were studied in accordance with standard methods, taking into account regulatory documents of Russian and foreign standards. Thermokinetic, X-ray phase analysis, scanning electron microscope investigation with an integrated system of energy-dispersive analysis were also applied. **Results and discussion.** It has been proved that highly dispersed WC, TiC powder additive to cement materials leads to increase in density, paste fluidity, reduction in setting time, decrease in water absorption, porosity, and increase in strength characteristics both in early and later periods of hardening. A highly dispersed additive promotes earlier hydration. The structure of the cement sample with powder additive is denser throughout the considered periods of hardening compared to the control sample. **Conclusion.** The obtained results are of great importance for understanding the action mechanism on cement materials of highly-dispersed particles of WC, TiC, which can later be used to improve the properties of composite cement-based materials in various fields of application.

KEYWORDS: composites, additive, high-dispersive powder, modification, tungsten carbide, titanium carbide, strength.

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INTRODUCTION

The Production cost of composite materials for construction purposes is primary determined by the cost of binders, which have a significant potential in improving the physical and mechanical characteristics [1–6]. It is known from the scientific literature [7–13] that the most in-demand technological method for improvement the quality of cement concretes is the introduction of modifying additives. For this purpose, nano-sized additives are of particular interest, the use of which improves the pore structure and physical and mechanical properties, and also gives cement materials additional or improved properties such as: plasticity, weight reduction, self-compaction, self-cleaning, improved air quality, self-restorability, as well as longer durability.

Commonly available and well-studied nanoadditives that quite close in composition and type of chemical bonds, and physical and chemical characteristics to the initial binders and hydration product are such as: SiO_2 nanoparticles in various forms (pyrogenous nanopowders; nanopowders precipitated from Na_2SiO_3 solution; SiO_2 colloidal sol; nano-SiO_2 in combination with other components, etc.) [14–16], aluminum oxide nanopowder Al_2O_3 [17–20], $CaCO_3$ nanopowder [21], titanium oxide TiO_2 [22–24], etc. Carbon nanoparticles (fullerenes, nanotubes, astralenes, etc.) have found application as nanosized inert additives, chemically inactive to cement systems in cement composites [25–28]. Many scholars [29–36] consider the addition of a combination of nanoparticles is more effective in improving the mechanical properties of concrete than customized usage of additives.

The study [37] examines the role of SiO_2, $CaCO_3$ and $Ca(OH)_2$ nanoparticles, which are replaced in cement in various binary and ternary combinations by changing the dosage of 2% and 5% by mass. The results of the experiments showed that the mechanical properties of concrete mixtures were improved by 10–45% due to the additive of nanomaterials in optimal dosage; which in a triple combination is 2% and 5% for increasing corrosion resistance. However, higher durability results (from 5% to 60%) were achieved in the binary combination with 2% replacement.

According to the authors of [38], the combination 0.5% nanosized alumina Al_2O_3 and 1% nanosized titanium dioxide TiO_2 by mass of cement, leads to a compact and dense microstructure with fewer pores, which results in a high optimization of mechanical properties. Compared to the control sample, compressive strength, tensile strength and bending strength have increased by 42%, 34% and 28% respectively. The nanoparticles provide nucleation sections for extra C–S–H gel formation and control the growth of $Ca(OH)_2$ in the cement system.

Currently, there has been much research devoted to the study of nanoparticles mix effect on physical and mechanical properties of cement materials in combination both with industrial [39–46] and agricultural waste [47–49].

The combination of 10% waste textile sludge with 3% nanostructured alumina provides improved strength and durability characteristics of cement concrete. The additive of aluminum oxide nanoparticles has a dual effect, improves hydration properties, as well performs as a filler [41].

In the study [44] authors have developed new types of concrete mixtures with improved adhesion zone and strength characteristics containing 30% rubber crumb (from rubber tire waste) as a substitute, where ordinary Portland cement was replaced by 20% crushed blast-furnace slag and various contents of nanoparticles from glass bottles waste (3, 6, 9 and 12%). Microstructure analysis of the concrete mixtures has showed the formation of dense gels and fewer pores with acceptable technical properties.

The authors [47] have found that the combination of Al_2O_3 nanoparticles with a content of 3% and 10% rice husk ash, when creating modified cement concretes with increased strength and durability characteristic, turned out to be effective and productive for an environmentally friendly concrete material. When using sugar cane waste ash as a replacement for cement and nanosilica in the range of 1 to 6% by weight of cement, an increase in compressive strength by 80% and flexural strength by 90% was achieved compared to the control sample [49].

Due to the complex manufacturing process, the high production cost of nanomaterials, and the lack of large-scale production technology, the use of nanopowders as additives in cement materials significantly increases the cost of construction, therefore, they are not widely used in practical civil engineering. The exception is technologies where nanodispersed materials are formed as a by-product or from processing waste in various enterprises, which do not require high production costs, taking into account current trends of resource and energy saving. One such technology is the production of nanopowders from tungsten-containing scrap of solid alloys such as Tungsten-Cobalt alloys (WC+Co), Titanium-Tantalum-Tungsten-Cobalt alloys, Titanium-Tungsten alloys, Tungsten–Nickel–Iron (W+Ni+Fe), etc. [50]. However, as there is a lack of research on the possibility and feasibility of using nanosized tungsten-containing powders as additives in cement composites, it is relevant to determine the effectiveness and feasibility of their use. It requires a comprehensive study, which will expand the range of modifying additives for cement materials.

Current study presents the research results of the introduction of a highly-dispersed powder, consisting of tungsten and titanium carbides mixture, obtained from production scrap of solid alloys, on the change in the structural and physical and mechanical properties of cement materials. The choice of the additives is due to the variability of properties, as shown by previous studies [51–52], associated with the specificity of obtaining process, as well as the cost and uniqueness of the powder structure.

MATERIALS AND RESEARCH METHODS

The following materials were used as starting materials in the study of cement composites: Portland cement CEM-II / A-P42.5N (JSC Verkhnebekansky Cement Plant, Russian Federation; see Table 1 for chemical composition; specific surface area 340 m²/kg, specific density 2.26 g/cm³, standard consistency 25%); marine gray building sand, fineness modulus 1.5–2 mm (LLC SK PRIBOY, Russian Federation); high-dispersive powder consisting of a mixture of tungsten and titanium carbides (WC, TiC) (LLC Nanotech VG, Russian Federation).

As a modifying additive, we used a powder of a mixture of tungsten and titanium carbides, that was obtained

Table 1

Chemical composition of Portland cement (mass %)

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	LOI
24.93	4.47	4.11	58.99	0.86	2.92	2.70

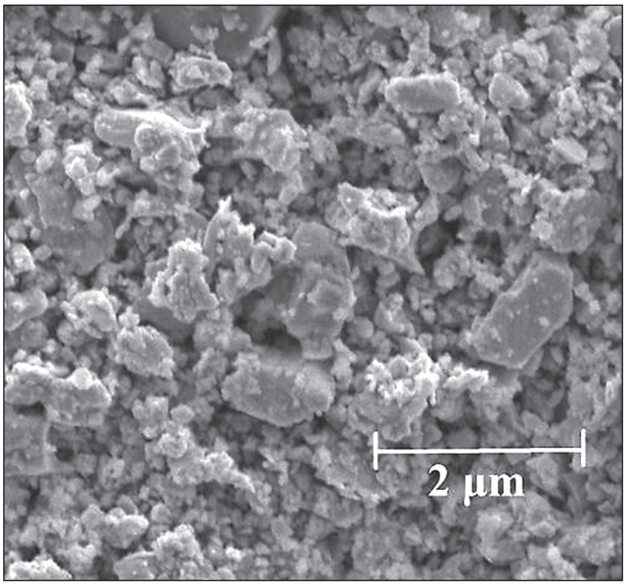

Fig. 1. **Micrograph powder mixture of tungsten carbide and titanium carbide**

as recycling result of solid alloy wastes from production of the Tungsten–Cobalt (WC+Co) type products (tungsten carbide WC, titanium carbide TiC, binder component cobalt Co) [50]. The surface area of the powder is 2.1 m^2/g. Specific density is 11.7 g/cm^3. The powder consists mainly of two phases – titanium carbide TiC with a cubic crystal structure and tungsten carbide WC with a hexagonal crystal structure. Composition of elements is WC – 93÷95% mass, TiC 7÷5% mass. Powder purity level is 99.5%. The powder is a mixture of particles of various shapes and their agglomerates. The morphology of the particles is inhomogeneous, mostly irregular in shape. Particle size less than 150 nm, agglomerate size from 300 nm to 1.5 µm.

The cement mixture was prepared according to the proportion indicated in Table 2.

To obtain cement stone, we made samples from the cement paste in the form of a cube 20×20×20 mm in size. The first full day the samples have been hardening in the molds in water, and after removal from the mold until the testing (on the 28th day of hardening) in a bath with a hydraulic seal at an ambient temperature of 20±2^{o}C and a relative air humidity of at least 90%.

When making sand-cement mixtures, the following fixed factors were taken: cement-sand ratio C/S = 1:3, water-cement ratio W/C = 0.4. For each experiment, six samples were prepared and poured into beam molds (4×4×16 cm). All specimens were compactly vibrated on a shaking table for better compaction and removed from molds after 24 hours of curing at 100% relative humidity and stored in a bath with a hydraulic seal at an ambient temperature of 20 ± 2^{o}C and a relative air humidity of at least 90% until testing on compression and bending (the 3rd, 7th, 14th and 28th days of hardening).

The cement paste spreadability (studies were carried out using a mini-cone. The cement paste was prepared according to the Table 2. The total ratio of water and binder (where «binder» was defined as Portland cement + additive) was W/C = 0.45. A mini-cone (upper diameter 19 mm, lower diameter 38 mm and height 57 mm) was placed on a glass platform, filled with cement paste; and excess paste was removed from the cone and platform. The we lifted the cone smoothly the vertically to minimize inertial effects. Spreadability was determined by measuring the flow diameter in mutually perpendicular directions and the average was calculated. Each sample paste was tested three times using three separately mixed batches of paste.

It is quite difficult to achieve an even distribution of highly dispersed particles in the mixture, particularly in powder form, therefore, an important operation of the technological process is the method of introducing an additive into cement [53]. There are three methods of the additive input to the cement mixture that have been studied: 1 – blending the powder with mixing water is carried out with an overhead mixer for 5 minutes, then the resulting suspension is introduced into the raw mixture; 2 – cement dry mixing with the powder additive have been carried out in a C 2.0 «TURBULA» mixer (St. Petersburg, VIBROTEKHNIK LLC) for 5 minutes, then mixing water is introduced; 3 – the powder under study is subjected to two-stage ultrasonic dispersion in the water environment for 30 seconds at a frequency of 22 kHz to break large agglomerates, and 30 seconds at a frequency of 44 kHz for more efficient deagglomeration of particles using an ultrasonic disperser UZD-22/44 (Ukraine). The criterion for assessing the method effec-

Table 2
The cement mixture proportions

	The content of components in the cement mixture, g					
Marking	M0	M1	M2	M3	M4	M5
Cement, g	400	396	392	388	384	380
WC, TiC Powder additive, g	–	4	8	12	16	20
Content of WC, TiC in the mixture, %	0	1	2	3	4	5

tiveness when introducing an additive into cement is the compressive strength of the cement stone on the 28th day of hardening, 6 samples for each type of study.

The study of water absorption was carried out on cubic shape samples 20x20x20 mm in size. All the samples were dried at 80°C for 24 hours to minimize damage to the microstructure from overdrying, then placed in water containers at a constant temperature (20±2°C). The samples were weighed every 24 hours of water saturation with an accuracy of 0.01 g. The samples had been in the water until the weighing results differed by no more than 0.01 g from the previous weighing. According to the degree of water absorption by mass and volume and the values of the solid density and mass specific gravity of the cement stone, the total porosity was calculated.

To study the strength properties, the prepared cement-sand samples have been kept for 3, 7, 14, 28 days, and then tested for compressive and bending strength. For each sample, at least six samples were tested for each type and age of the sample, the results were averaged. The study of physical and mechanical characteristics was carried out using a universal testing machine TRM-500 «Tochline» (LLC «Plant of Testing Instruments» (PTI), Ivanovo, Russia, the maximum limit load is 50 kN).

For determining the particular qualities of hydration and the effect of WC, TiC additives on cement properties in terms of heat release dynamics, a ToniCAL Trio (Computer controlled isothermal heat flow calorimeter) was used at a temperature of 20°C (Toni Technik Baustoffprüfsysteme GmbH, Germany). The measurement duration was 72 hours, the water/binder ratio was 0.5. Sample weight was10 g.

The materials crystal structure was studied with X-ray diffraction (ARL X'TRA, Thermo Techno) with a CuKα source in the angle range 2θ from 4° to 56° in the asymmetric coplanar survey mode with a grazing incidence angle $\alpha = 3^{\circ}$ (θ-scan). Phase identification and peak indexing were carried out using the ICDD (International Center for Diffraction Data) JCPDF database.

The cleavage microstructure of the studied cement samples on the 3rd, 7th and 28th days of hardening was studied using a PHENOM pro X scanning electron microscope from Phenom–World B.V. (Netherlands) with an integrated energy-dispersive analysis system. Maximum magnification is 150000, resolution – 10 nm, accelerating voltage – 5, 10, 15 kV.

RESULTS AND DISCUSSION

Spreadability of cement paste

Study results in changing the flow diameter for cement mixtures in the control composition (M0) and with the additives of 1–5 wt. % powder WC, TiC (M1-M5) are presented in Figure 2.

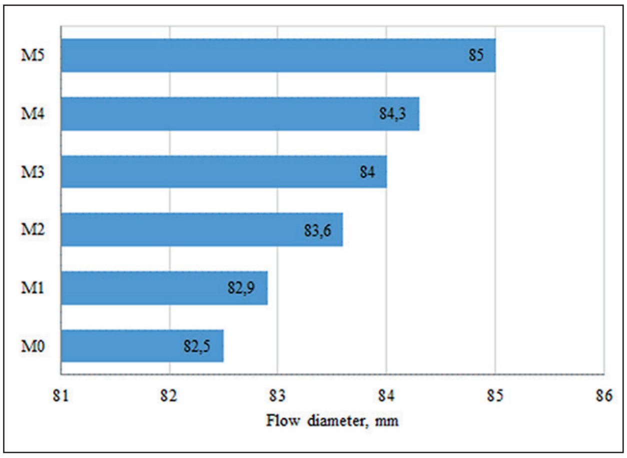

Fig. 2. **Cement paste spreadability study results**

The results show that with the increasing the additive percentage WC, TiC (1–5 wt.%) in the cement mortar, the flow diameter also increases, compared to the control mixture by 0.4–3%, respectively. Tungsten carbide and titanium carbide powder does not come into chemical interaction with cement components. As studies [32, 54] have shown, the introduction of highly dispersed inert particles (particle agglomerates) that act as a filler increases the lubricity of the cement paste. By occupying the empty space between the larger particles, they release free water, thereby increasing the amount of water available in the system to improve fluidity. That is, the additive acts as a lubricant, increasing the fluidity of the solution.

Setting time and density

Setting time was determined using a Vicat apparatus. The study results for the effect of high-dispersive powder mixture WC and TiC on the setting time of Portland cement are presented in Figure 3.

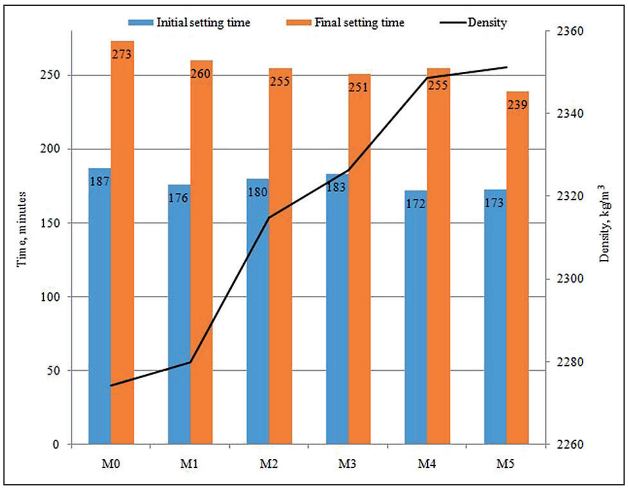

Fig. 3. **Cement paste setting time results**

As we can see in Figure 3 with an increase in the content of WC, TiC powder in the additive composition, cement samples density increases. This can be explained by the high specific density of the studied additive compared to the specific density of Portland cement. With a minor amount of additives WC, TiC (up to 1%), a slight increase in density (by 0.3%) is observed, in case of an additive content (4–5%), the density increases by more than 3%.

The setting time for cement samples modified with powder at a modifier concentration of 1–5 mass % is reduced: the initial setting decreases by 7.5%, the final setting – by 12.5%, which may be from both a decrease in the cement proportion due to additives WC, TiC, and with an increase in the degree of Portland cement hydration; as well as the presence of a large number WC, TiC particles in the liquid phase, which act as seeds for the new formation, which in turn also contributes to the acceleration for crystallization process and the setting acceleration.

Influence of the introducing additive method into the cement mixture

Influence of sequence methods when introducing additive into the cement mixture on the properties of the cement stone is presented in Figure 4.

As we can see from the study results (Fig. 4), to method 1 the influence of the introducing method for the powder into the cement mixture on the change in the strength properties of the samples is not significant, the maximum increase in compressive strength is 13% (at a content of 3 wt.% WC, TiC), which associated with the agglomeration of powder particles in water.

With dry mechanical mixing, the increase in the cement strength stone reaches 22% (with the addition of 1 wt.% WC, TiC), with the preliminary ultrasonic treatment of the suspension, the increase in the sample strength is 41% (with the addition of 2 wt.% WC, TiC) compared to the reference sample. This fact is explained by deagglomeration and dispersion of highly dispersed particles in a liquid as a result of ultrasonic exposure, and as a result, an even particles distribution in the volume of the cement material.

With an increase in the content of high-dispersive powder more than 2 mass % the strength of the cement stone is reduced. This may be due to the fact that, firstly, tungsten and titanium carbide do not have cementing properties, therefore, excessive replacement of cement must have led to a decrease in compressive strength, and secondly, as a result of significant agglomeration of powder particles at a dosage of more than 2 mass %. The results obtained are consistent with the data of other researchers [26, 55]. They noted that an excessively high dosage can lead to “poisoning” of the system, a significant slowdown in the processes of hydration and hardening.

Analyzing the results on assessment the influence of the methods introducing additives into the cement paste, as well as the amount of additive content on the properties of the binder, we can to determine the rational ratio of highly-dispersed additives in the cement matrix, equal to 1–2 mass % (an increase in strength is 23–41%).

Water absorption, total porosity

Table 3 shows water absorption and total porosity values of cement stone. The addition of 1–2 mass % highly-dispersed particles reduce the water absorption index by

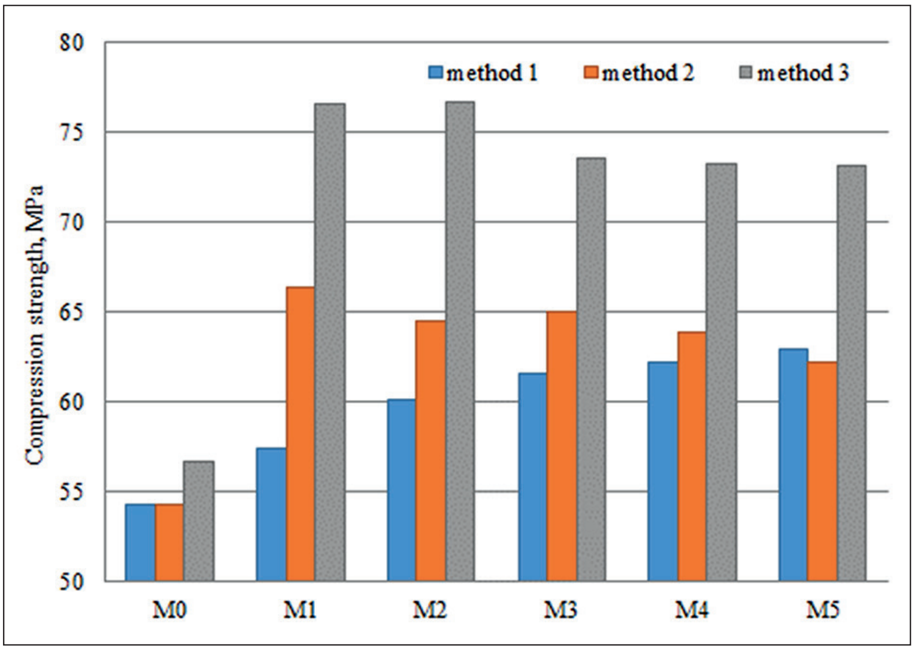

Fig. 4. **Study Results. Influence of the introducing additive method into the cement mixture on the cement stone strength:** method 1 – blending the additive with water; method 2 – dry mixing of the additive and cement; method 3 – ultrasonic dispersion of the additive in water environment

Table 3
Water absorption and porosity of cement stone

Marking	M0	M1	M2
Water absorption of cement stone by mass, %	5.09	4.31	4.13
Volume of open capillary pores, %	10.50	9.32	9.04
Total pore volume of samples, %	15.23	12.55	12.05
Volume of air nominally-closed pores, %	4.72	3.23	3.00

15–19%, the total porosity by 31–36%. The decrease in porosity is consistent with the results presented above (Fig. 4), with an improvement in compressive strength due to the formation of a denser structure with the inclusion of a highly dispersed additive WC, TiC.

Cement-sand samples strength kinetics development in compression and bending

The major indicators for performance properties of cement materials are change of their kinetic characteristics over time. Figure 5 shows graphs characterizing the kinetics of compressive and bending strength of cement-sand samples with 1 wt.%, 2 wt.% highly-dispersed additives WC, TiC.

The results show that the introduction into the cement-sand the powder mixture of WC, TiC leads not only to an increase in the final compressive strength (on the 28th day of hardening), but also to an increase in the early rate of strength development of the samples starting from the age samples of 3 days. From the graphs it can be seen that there is an intensive increase in strength in the initial period of hardening for the reference sample, then a gradual decrease occurs in the rate of strength development. Portland cement modified with the additive mixture of WC, TiC has another type of strength growth. Strength development has been increasing for almost 28 days.

In particular, the compressive strength of the cement paste on the 28th day of hardening with the addition of 1–2 mass % WC, TiC, was improved by 59–63%, the bending strength was increased by 30–35%, respectively. As can be seen from the results, the most optimal concentration of the additive is 1 mass %; further studies have been carried out with the optimal concentration additive.

To explain the above obtained results and to detection the regularity of the composition formation, structure and properties of cement stone, thermokinetic studies, X-ray phase and electron microscopic analysis of control and modified samples of cement stone have been carried out.

Thermokinetic studies of the processes of the early stage of hydration of binders

In order to confirm the above obtained results, thermokinetic studies have been carried out (Table 4, Fig. 6), aimed at identifying the features of hydration of the binder with the addition of 1 mass % additives WC, TiC powder, determined by the dynamics of heat release indicators, expressed by the dependence $dQ / dt = f(t)$ during the initial period of hardening, and the total amount of heat released, described by the function $Q = f(t)$ for 72 hours, with a differential calorimeter.

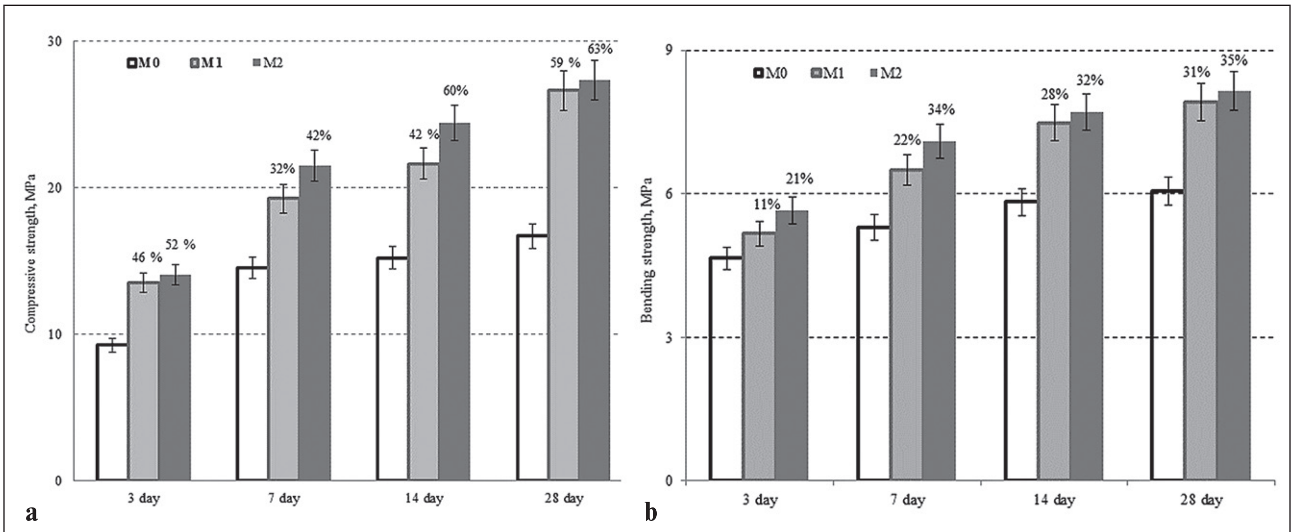

Fig. 5. **Kinetics of strength development in compressing (a) and bending (b) for cement-sand mortar of the composition M0 and M1, M2**

Table 4
Characteristics of thermokinetic indicators

№ Sample	Sample	Start of reaction, sec	Exo-effect			Heat release, max. for 72 h, J/g
			The time of reaching h:min:sec	Maximum value J/g • h	Heat release, J/g	
1	Portland cement	15	0:05:31	16.53	1.08	209.9
			13:03:10	8.11	70.11	
2	Portland cement + 1% WC, TiC	15	0:06:01	15.82	1.15	202.2
			12:51:31	7.76	67.38	

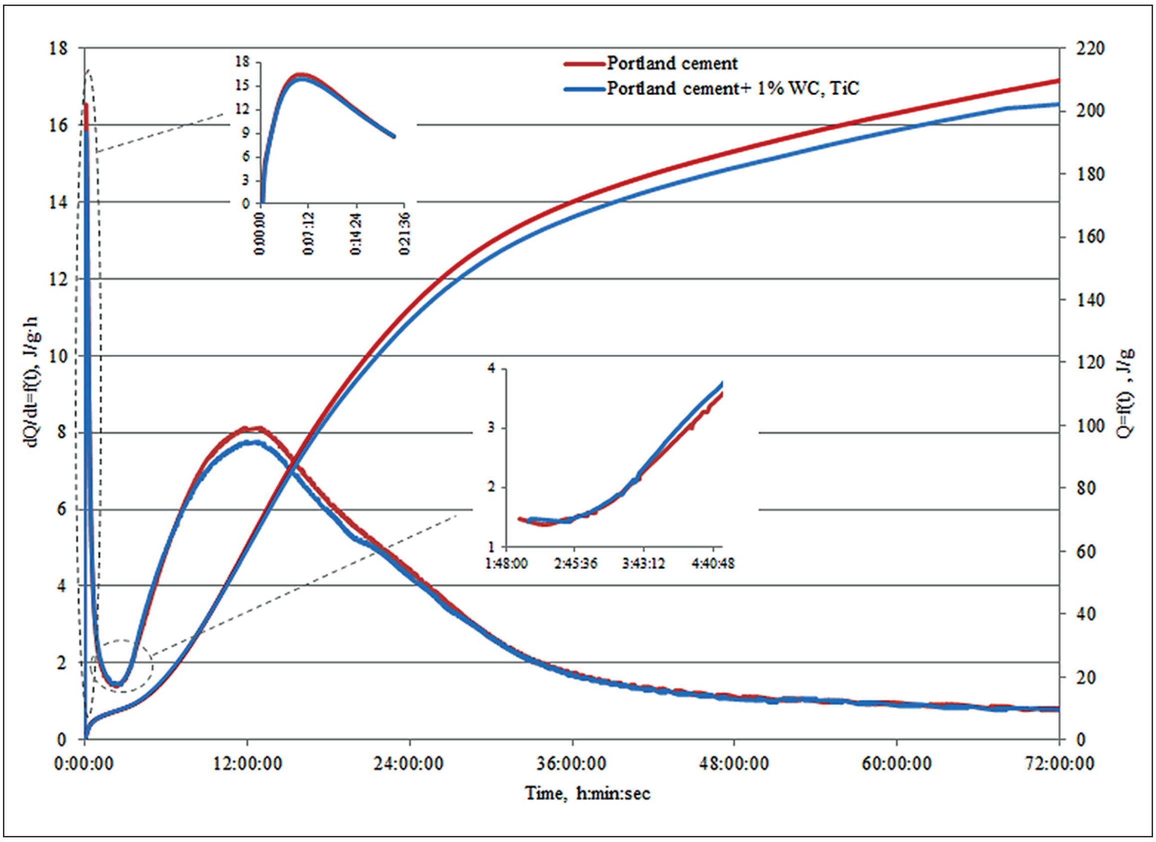

Fig. 6. **Differential and integral curves of heat release during hydration of the studied samples**

The first peak, which falls on a period of 4–7 minutes (Fig. 4), is associated with the process of exothermic wetting, as well as the reactions of the early stage of hydration. After 5 min 30 sec gauging, the studied systems show an intensive increase in heat release (Table 4). Its origination is associated with the dissolution of minerals that form the surface of the clinker particles. Further, the rate of cement interaction with water decreases as the solution is saturated with primary hydration products, the system enters the induction period (no significant effect of WC, TiC powder was observed for that period), after which a repeated increase in the level of heat release of the system under study is observed – the period of active hydration. As the results of our study show, the use of WC, TiC additives accelerates the start of this period (Table 4). This may be due to the accelerated heterogeneous nucleation of hydrates on particles of highly-dispersed powders. However, despite the acceleration of the appearance of the main peak of hydration, there is a decrease in the intensity of heat release for compositions with additives, in relation to the control one, which is due to a decrease in the content of Portland cement in the mixture and a change in the amount of the liquid phase relative to cement.

X-ray phase analysis of cement stone

Comparative X-ray phase analysis of the control cement hydration products and cement with 1% WC, TiC additives is presented in Figure 7.

According to X-ray phase analysis, when 1 mass % WC, TiC additive is introduced into the cement mixture, the diffraction pattern shows a tendency to a decrease in the intensity of the peaks of Portlandite $Ca(OH)_2$ and peaks of clinker minerals (C_3S and C_2S), as well as an increase in the intensity of the peaks belonging to calcium hydrosilicates , in comparison with the control composition, leading to an increase in the physical and mechanical characteristics of the strength of the cement stone, which is additionally confirmed by the results of the microstructural and thermokinetic analysis, as well as mechanical tests of the developed compositions.

Microstructure of samples

In order to study the microstructure and to explain the origin for the increase in the strength characteristics of the cement material with the addition of a highly-dispersed powder, an electron microscopic study of the cleavage surface microstructure of cement samples was carried out with magnification of x 10,000 times on the 3rd, 14th, 28th day of hardening (Fig. 8).

As can be seen from the presented micrographs (Fig. 8, a), there is a heterogeneity of the structure, a large volume of open pores and voids in the control sample,

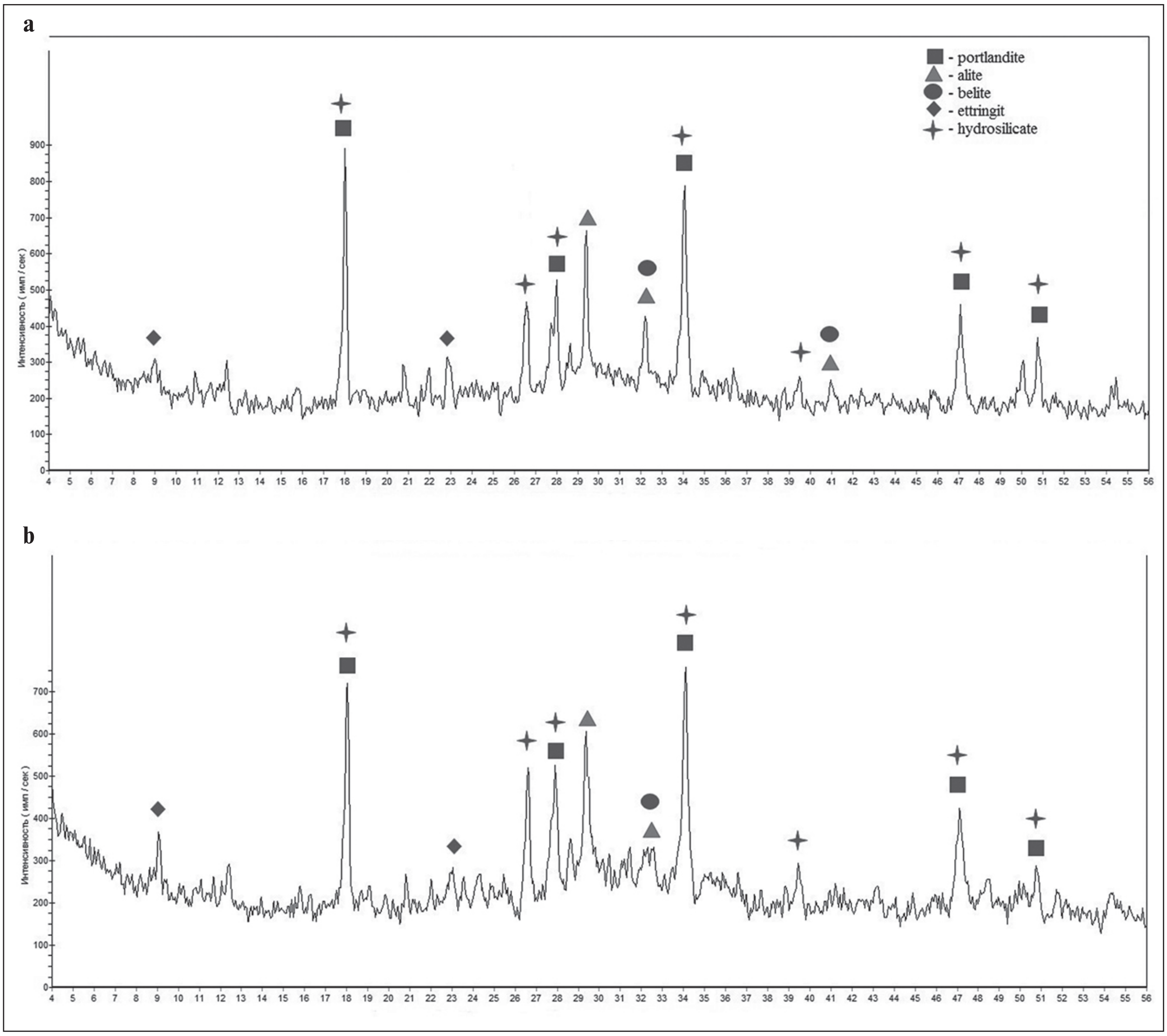

Fig. 7. **X-ray of the control composition cement stone (a) and modified with 1 mass. % WC, TiC powder (b) at the age of 28 days**

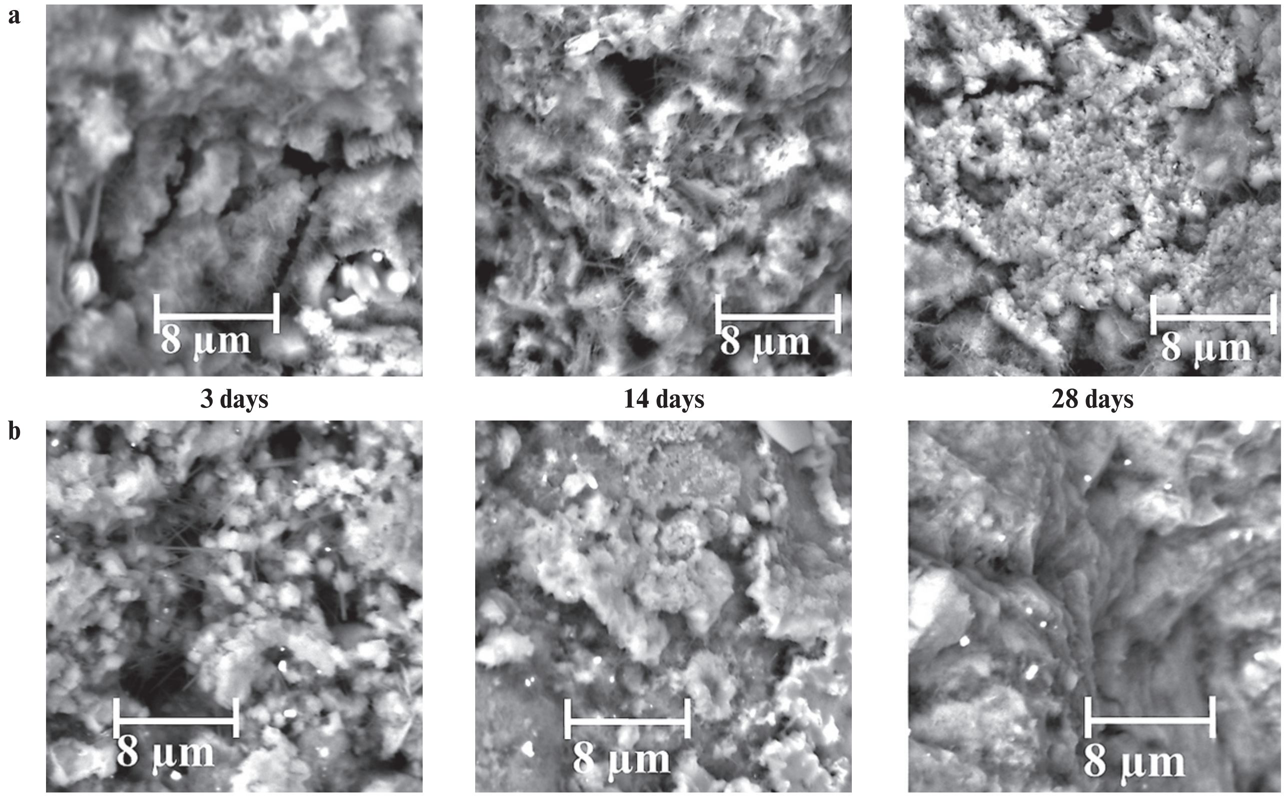

Fig. 8. **Microstructure of cement samples from the control composition (a) and modified with a mixture of WC, TiC powders (b) at the age of 3, 14, 28 days**

despite the cement paste achievement of hydration on the 28th day of hardening. The structure of the cement sample with the powder additive (Fig. 8, b) is denser in all the considered periods of hardening compared to the control sample.

CONCLUSION

The article is focused on the study of the effect from the content of highly-dispersed WC, TiC powder on the properties of cement pastes and cement stone: changing the setting time, spreadability, compressive strength and bending. We also analyzed the effect of WC, TiC additive on thermokinetic parameters, hydration products and the microstructure of cement hardening pastes. From the above research process, the following conclusions can be drawn:

– With an increase in the percentage of additives of 1–5 mass % WC, TiC in the cement mortar, the spreading diameter increases by 0.4–3% compared to the control mixture, the density of cement samples increases by 0.3–3%, respectively. The initial and final setting time of the modified samples decreased with an increase in the content of the additive by 7.5%, the end of setting – by 12.5%.

The article considers the issues related to the ways of introducing a highly-dispersed powder into the cement mixture and hence the strength change in properties of the samples. With dry mechanical mixing, the increase in the strength of the cement stone reaches 22%, when using ultrasonic treatment of an aqueous suspension, more than 41% compared to the control sample.

– The addition of 1–2 mass % highly-dispersed particles reduce the water absorption index by 15–19%, the total porosity by 31–36%, respectively. The decrease in porosity is consistent with the improvement in compressive strength due to the formation of a denser structure with the WC, TiC additive.

– A categorical tendency to increase the strength characteristics was revealed when the powder of the WC, TiC mixture was introduced into the cement-sand mixture, both in the early and later periods of hardening (on the 28th day of hardening). In particular, the compressive strength of the cement paste on the 28th day of hardening with the addition of 1–2 mass % WC, TiC, was improved by 59–63%, the bending strength was increased by 30–35%, respectively.

– The addition of a highly dispersed additive contributed to earlier hydration. Those could be due to the accelerated heterogeneous nucleation of hydrates on powder particles. There was a decrease in the intensity of heat release of compositions with additives, in relation to the control one, which was due to a decrease in the content of Portland cement in the mixture and a change in the amount of the liquid phase relative to cement.

– X-ray phase analysis of the hydration products of the control cement and cement with 1% additive WC, TiC showed a decrease in the intensity of the peaks of portlandite and clinker minerals, as well as an increase in the intensity of the peaks belonging to calcium hydrosilicates, compared with the control composition, leading to an increase in the physical and mechanical characteristics of cement stone strength.

– According to data from scanning electron microscope (SEM), the studied powder effectively reduced voids and defects in cement-based materials, making the structure denser, while the composition of hydrated phases in cement pastes was not violated by the addition of highly-dispersed additives, which in turn not only interferes with the normal passage of the system through each stage of hydration, but also accelerates hydration.

A mixture of highly-dispersed WC and TiC powders, obtained from hard-alloy waste, can be used as a modifying additive for cement materials in the production of both structural and special-purpose concretes (hydraulic, radiation-resistant, etc.).

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