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INTENSIVE SEPARATE TECHNOLOGY AND ITS INFLUENCE ON THE PROPERTIES OF CEMENT-WATER COMPOSITIONS, SOLUTIONS AND CONCRETES ON THEIR BASIS

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Abstract. The article reviews the issues related to the mechanical activation of Portland cement in the separate technology of the production of concrete mixtures in the production of concrete and reinforced concrete products. Usually, an essential characteristic of composite building materials based on Portland cement and its varieties used in building processes is their rapid setting of strength. Therefore, scientific researches related to the development of technologies aimed at the intensification of cement hydration processes and the growth of the speed of concrete strength gaining are relevant. The work presents the main technological processes during the production of concrete mixtures using intensive separate technology. The usage of this technology, particularly, makes it possible to significantly increase the reversibility of forms due to a more intense concrete strength gaining on mechanically activated Portland cement, especially during the early stages of hardening. The need to include mineral filler in the form of ground quartz sand during the preparation of the cement-water composition in a high-speed mixer is founded. It was experimentally discovered that the rapid mixing of the cement-water composition in the presence of a C-3 superplasticizer causes a sharp decrease in its effective viscosity, which positively affects the reduction of the water content of concrete mixtures of the required ease of workability.

The mechanical activation of Portland cement causes an increase in the amount of chemically bound water in vintage-age cement stone from 13.1% to 17.9%, which means more than 36% compared to the control. It was established that with the same amount of binder, the strength of the concrete on activated Portland cement on the first twenty-four hours of hardening is 1.8...2 times higher compared to the concrete of similar composition, the binder of which was not activated. Over time, the effect of activation on the concrete strength decreases a little, but even at 28 days, the compressive strength of concrete on the activated binder is 25…30% higher compared to the control.

Keywords: concrete, separate technology, tribo-activator, filler, mechanical activation.

Introduction. In the building industry, there is a search for new techniques aimed at speeding up the building process. These methods can be conventionally divided into two types: organizational – the organization of building production, planning, and building management, and technological – the use of new composite materials, machines, units, and equipment.

Among the list of requirements for the technology of manufacturing products on ordinary, standard Portland cement, high importance is paid to the accelerated concrete strength gaining, especially in the early stages of hardening. The use of fast-hardening cement for these purposes is very limited for a number of reasons, including their high cost. Intensification of the concrete hardening process with the help of heat-moisture treatment is currently economically unjustified due to excessively high tariffs on the heat. Therefore, in our opinion, the search for a new technological method is particularly relevant, which will allow to dramatically accelerate the processes of structure formation of cement-containing composites and obtain concretes with high early strength under normal hardening conditions.

Analysis of recent research and publications. In concrete science, great attention is paid to the study of the properties of the concrete mixture, their optimal composition, as well as rational methods of mixing and compaction to obtain concrete of a given quality [1-3]. Aspects of improving the technology of manufacturing concrete mixtures include: a) modernization of existing types of mixing plants and creation of new types of mixers; b) finding the optimal sequence of loading and mixing the components of the concrete mixture; c) the development of complex recipe-technological methods combining intensive methods of making concrete mixtures with the adding of mineral fillers and chemical additives into their composition, which purposefully regulates the properties of both concrete mixtures and concretes based on them; d) automation of concrete units and so on [4-7].

Turbulent mixers of various constructions are increasingly used in the practice of preparing concrete mixtures. Their use makes it possible to solve issues related to improving the homogeneity of the concrete mixture and increasing the strength of concrete in the vintage age. In this sense, intensive separate technology (IST) for the preparation of concrete mixtures is promising [8-12]. Its use involves the separation of the concrete mixture production process, namely: a) an activated highly concentrated cement-water composition is prepared in a high-speed mixer; b) in a traditional (ordinary) concrete mixer, the dosed for the batch fine and coarse filler is mixed with the cement-water composition to a homogeneous state. The use of high-speed hydrodynamic mixing for cement activation in combination with optimal by its quantity and by the dispersion of mineral fillers, effective additives, and superplasticizers provides, along with plasticization, a sharp acceleration of cement hardening processes, which allows abandoning both the use of quick-setting cement and heat-moisture treatment.

The aim of the research. The described above purposed this work, to determine the influence of mechanical activation of Portland cement on the properties of cement-water compositions, mortars, and concretes based on them.

Research materials and methods. Joint activation of Portland cement and ground quartz sand (specific surface of quartz particles 250 m^2/kg) was carried out by intensive circulation of the filled cement-water composition with V/T=0.27 in a high-speed mixer-tribo-activator. In the tribo-activator, along with the physical and chemical activation of Portland cement particles and ground sand, high homogeneity of the highly concentrated composition is ensured. While mixing, finely dispersed particles of binder and quartz sand are given high speeds and complex trajectories of movement. As a result of their collision with each other in the flow, as well as with the walls and blades of the activator, the degree of wettability increases, even distribution of water, physical and chemical dispersion, peeling off the shielding products of neoplasms from the surface of the binder particles with exposure of new active centers is ensured [9]. All this, in our opinion, will directly affect the acceleration of cement hydration and, as a result, the increase in strength of cement stone and concrete based on it, both in the early stages of hardening and in the vintage age.

Production of concrete mixtures was carried out both by intensive separate (with the use of mechanical activation of the binder in a tribo-activator) and by traditional technologies.

The work used the methods of physical-chemical and physical-mechanical researches (calorimetry, determination of the effective viscosity of cement-water compositions, the amount of chemically bound water, the compressive strength of samples from cement-sand mortar and concrete).

Portland cement PC II/A-Ш-400 (CEM II/A-S 400) with an activity of 41.0 MS, manufactured by "Yuhtcement" [a branch of JSC "Dyckerhoff Cement Ukraine"], which meets the requirements of DSTU (National Standard of Ukraine) Б В.2.7-46:2010, "Cement for general construction purpose. Technical conditions" was used as a binder in the research. Ground quartz sand with a specific surface area of 250 m^2/kg was used as mineral filler. For the plasticization of cement-water compositions, as well as mortar and concrete mixtures based on them, a condensation product of naphthalene sulfonic acid and formaldehyde was used – superplasticizer C-3. The consumption of the superplasticizer was assumed to be equal to 1% of the mass of the binder. As aggregates for concrete, quartz sand from the Oleksandrivskyi quarry in the Odesa region with a coarseness modulus of Mk=2.2 and granite crushed stone of fractions 5-10 and 10-20 mm were used in a ratio of 1:1 by the weight.

The evaluation of the structural characteristics of the cement-water composition – the effective viscosity η – was determined using a rotary viscometer "Polymer-RPE-1M".

Research results. Shown in the Fig. 1 graphical dependence of the effective viscosity of the modified cement-water composition on the duration of mechanical activation **τ** shows that high-speed mixing causes a sharp decrease in **η** (up to 30 times), reaching its minimum value after 150 seconds activation.

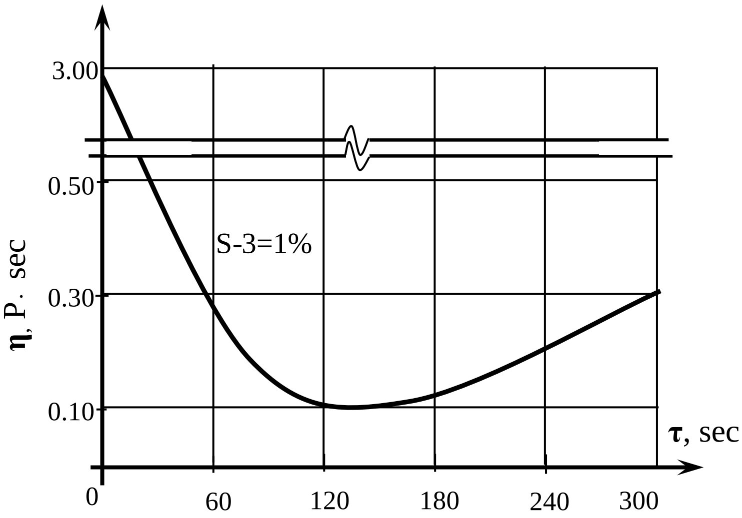

Fig. 1. The influence of the term of high-speed mixing of the cement-water composition on the change in effective viscosity η

Further high-speed mixing is accompanied by the thickening of the cement-water composition, which is fixed by the increase in the value of the effective viscosity. To identify the reason for such a change in the effective viscosity in the process of high-speed mixing of the cement-water composition, experiments were conducted in which three input parameters were simultaneously controlled:

– effective viscosity;

– temperature of the cement-water composition;

– water division.

For the purity of the experiment, it was assumed that there was no S-3 superplasticizer in the mixing water. It was found that the initial decrease in the effective viscosity of the cement-water composition is accompanied by a decrease in the amount of free water in it. At the moment when the effective viscosity of the cement-water composition reaches its minimum value, water division almost completely stops Fig. 2, b. In the following period, a more intensive increase in the mixture temperature is observed, which indicates an increase in frictional forces between cement particles in the process of high-speed mixing of the cement-water composition, Fig. 2, a. Thus, free water, being adsorbed on the newly created surfaces of the binder particles, gradually transits into a bound state and ceases to play the role of "lubricant", which leads to an increase in frictional forces, which is recorded by a more intensive increase in the temperature of the mixture (Δt_z) in comparison with heating (Δt_i) of the cement-water composition in the initial period of rapid mixing.

A sufficiently objective characteristic of the kinetics of the physicфд-chemical process of hydration of the binder is the exothermic heating of the hardening cement-water composition. The hydration temperature was determined using a thermal calorimeter. The choice of this method is due to the fact that it allows estimating of the hydration and structure formation processes over time, as well as quantifies the temperature change of the hardening composition.

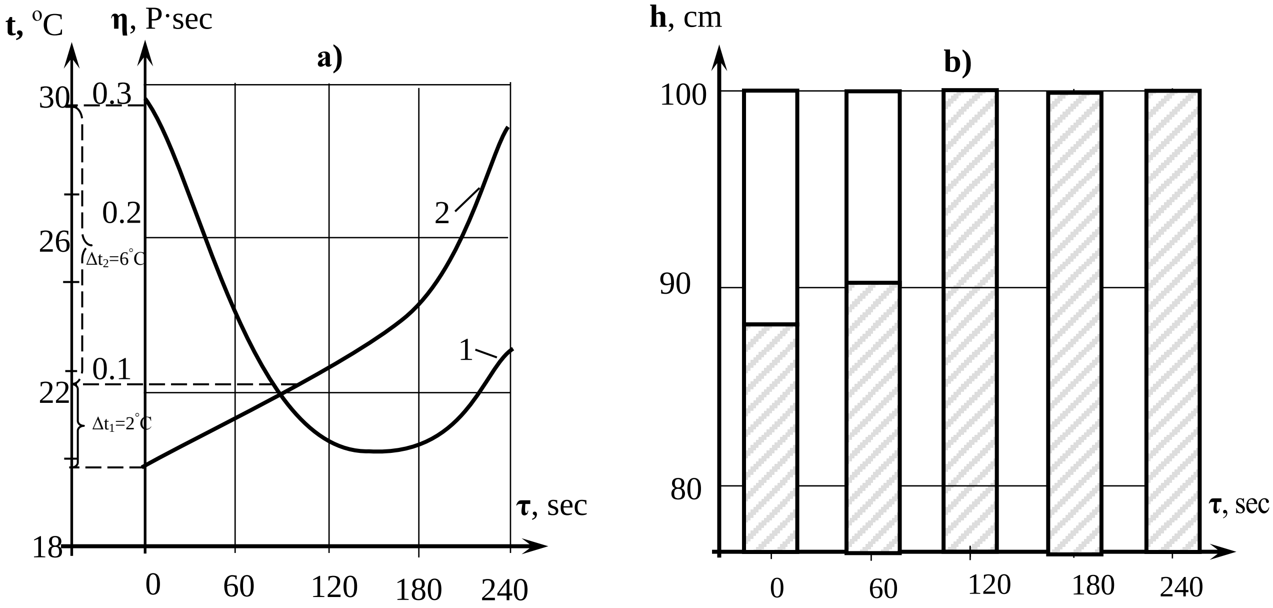

Fig. 2. The influence of the activation term **τ** on the effective viscosity, temperature (a) and water division (b) cement-water compositions:
1 – effective viscosity; 2 – the temperature of the cement-water composition
☐ – free water in the cement-water composition
▨ – cement-water composition

After 120 seconds of activation, the cement-water composition was placed in a container with a volume of 200 cm^3, which, in its turn, was installed into the calorimeter. The temperature of the hardening cement-water composition was measured using electronic sensors. For control, a cement-water composition was prepared, which was not subject to mechanical activation. As it can be seen from Fig. 3, the mechanical activation leads to an increase in both the rate of heating of the cement-water composition and an increase in the maximum heating temperature.

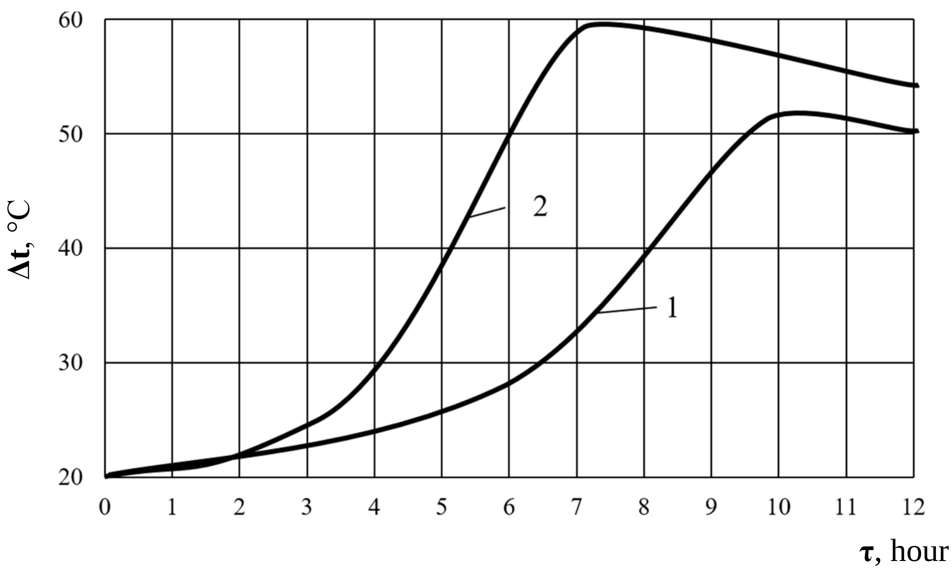

Fig. 3. Kinetics of exothermic heating of hardening cement-water compositions:
1 – control; 2 – mechanically activated Portland cement

Data on the content of chemically bound water in cement stone at the age of 1 day to 28 days of normal hardening at a temperature of +20°C confirm the increase in the rate of hydration of Portland cement due to its mechanical activation, Table. 1.

Table 1 – Amount of chemically bound water in the cement stone

Technology production	The content of chemically bound water, %, aged, day			
	1	3	7	28
Traditional manufacturing of cement-water composition	6.2	10.3	12.9	13.1
Mechanic-chemical activation of cement-water composition	10.2	14.1	17.2	17.9

Of particular interest was the effect of mechanical activation of cement on the growth kinetics of chemically bound water in cement stone during the first 24 hours of hardening, Fig. 4.

Attention should be paid to the fact that three hours after mixing, the amount of chemically bound water in the hardening cement-water composition on mechanically activated Portland cement and on cement that was not mechanically activated is practically the same and is in the range of 2.8% to 3.4%. However, already after 6 hours of hardening, there is a sharp increase in the amount of chemically bound water for mechanically activated cement – from 3.4% to 5.9%. For a traditionally prepared cement-water composition, there is a gradual increase in the amount of chemically bound water – from 2.8 to 3.4%. After 24 hours of hardening, the amount of chemically bound water in the activated cement-water composition is approximately 1.6 times bigger compared to the composition, the binder of which was not subject to mechanical activation. In the subsequent periods of hardening, the difference between the amounts of chemically bound water in the activated and non-activated Portland cement decreases, and at the vintage age does not exceed 27…37%.

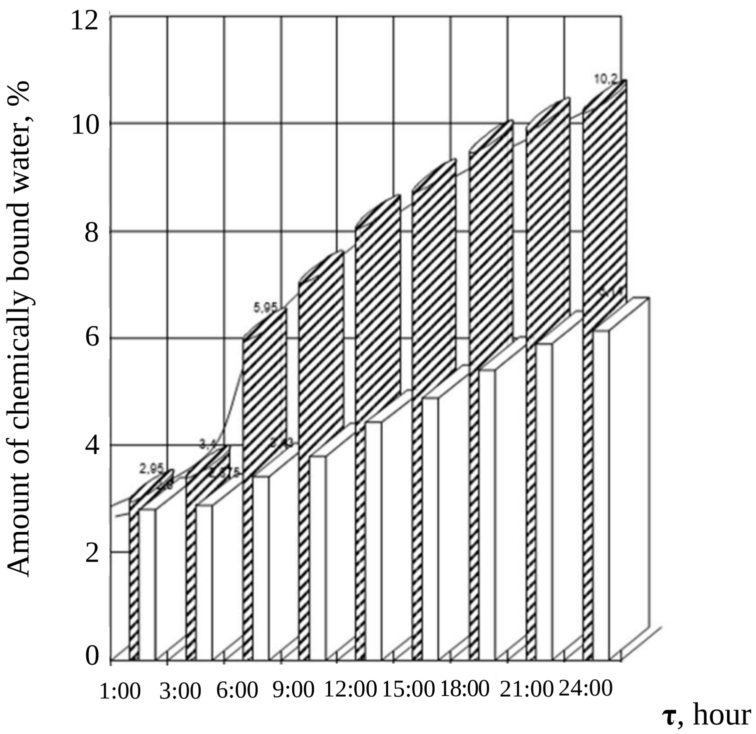

Fig. 4. The influence of mechanical activation on the kinetics of chemical binding of water in the hardening cement stone:

☐ – control;

▨ – mechanically activated Portland cement

The effect of mechanic-chemical activation of cement on strength was studied on cement-sand samples made from a mixture of composition – C:P = 1:3 with a water-cement ratio W/C = 0.4, Fig. 5.

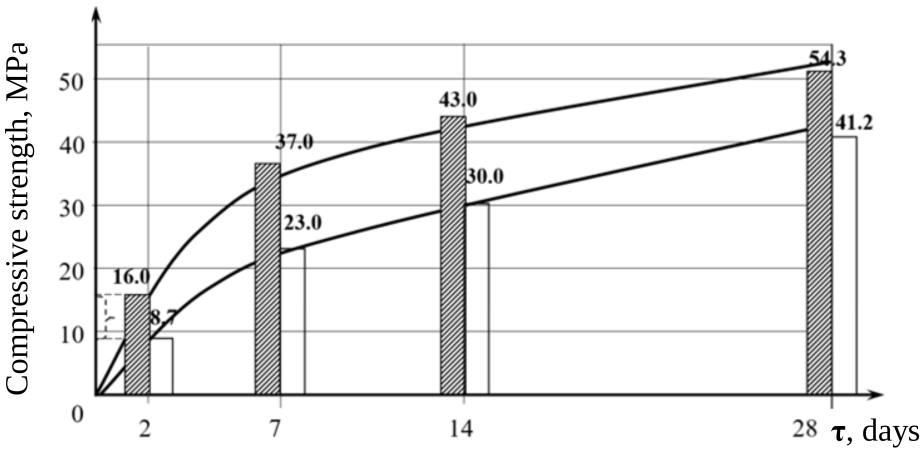

Fig. 5. The influence of mechanical activation on the strength of cement-sand mortar:
☐ – control; ▨ – mechanically activated Portland cement

The activated cement-water composition was mixed in a dosed amount of sand, and after compaction on a vibrating platform, the beam samples were hardened in 4×4×16 cm forms at a temperature of $+20^0$C. The kinetics of strength gaining of the cement-sand solution shows that the activation of cement leads to a more intense increase in the strength of the samples compared to the samples made on Portland cement, which was not subjected to mechanical activation.

This is especially noticeable in the initial stages of hardening. At the age of 2 days, samples on mechanically activated cement are characterized by 1.84 times higher compressive strength compared to samples made on a binder that was not subject to mechanical activation. At a later age, the strength of the samples evens out somewhat, and on the 28th day of hardening, the compressive strength of the samples on mechanically activated cement exceeds the strength of the control samples by no more than 30...32%.

Mechanical activation of Portland cement also significantly affects the strength of concrete. This is confirmed by the results of the compressive strength of concrete at the age of 28 days on the mechanically activated binder, as well as on the binder that was not mechanically activated (control), Fig. 6. In the experiment, the composition of concrete (cement: sand: aggregate = 1:2:4) was studied with the consumption of a mixed binder (Portland cement + ground sand) in the amount of 450 kg/m^3.

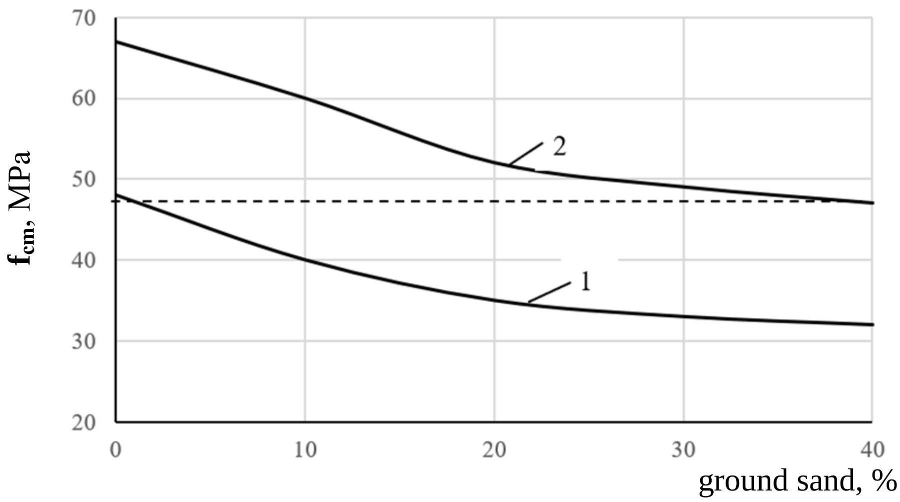

Fig. 6. The influence of the concentration of ground sand in Portland cement on the f_{cm} of concrete in the 28th day age:
1 – concretes, made according to traditional technology; 2 – intensive separate technology of concrete production

The mobility of the concrete mixture was assumed to be constant (concrete mix slump = 3 cm) and was corrected (depending on the consumption of ground sand in the binder) by the consumption of mixing water. The amount of C-3 superplasticizer was taken at the level of 1.0% (in terms of dry matter) of the binder consumption.

As the research results show, the replacement of a portion of Portland cement with ground quartz sand leads to a decrease in the strength of concrete made by traditional technology, Fig. 6 (curve 2), which coincides with the experimental data given in the work [13]. At the same time, the intensive separation technology for the production of concrete mixtures contributes to the gaining the concretes with a compressive strength 35...45% higher in comparison with concretes of similar composition, which are produced according to traditional technology, Fig. 6 (curve 2), due to physical and chemical processes considered in the work [10]. Thus, the second important advantage of IST over traditional technology is the resource-saving effect, which allows replacing up to 40% of Portland cement with ground sand, obtaining practically the same compressive strength characteristics of concrete as for concrete made by the traditional method, but without introducing Portland cement ground sand in the given range.

Conclusions:

1. The positive effect of high-speed mixing of cement-water compositions in the presence of C-3 superplasticizer on the reduction of their effective viscosity η was revealed. The combined effect of mechanical activation and C-3 additive provides a decrease in η up to 30 times compared to the effective viscosity of a non-mechanically activated cement-water composition of a similar composition.

2. Due to the mechanical activation of cement-water compositions, the amount of chemically bound water in cement stone of vintage age increases from 13.1% to 17.9%, that is, by more than 36% (compared to the control).

3. An important advantage of IST over the traditional technology is the resource-saving effect, which allows replacing up to 40% of Portland cement with ground quartz sand (S=250m^2/kg), while obtaining the same compressive strength of concrete at the vintage age, which is achieved by concrete on non-mechanically activated cement, but without the addition of ground sand (control).

References

[1] F. De Larrard, *Concrete mixture proportioning. A scientific approach*. London and New York, 1998.

[2] A.K.H. Kwan, L.G. Li, "Combined effect of water film thickness and paste film thickness on rheology of mortar", *Materials and Structures*, vol. 45, no. 1, pp. 1359-1374, 2012.

[3] A. Baule, F. Morone, H.J. Herrmann, H.A. Makse, "Edwards statistical mechanics for jammed granular matter", *Reviews of modern physics*, vol. 90, no. 1, pp. 015006-015064, 2018.

[4] M.A. Sanic'kij, H.S. Sobol', T.Є. Markiv, *Modifikovani kompozicijni cementi*. L'viv: Vid-vo L'vivs'koï politekhniki, 2010.

[5] G. Roquier, "The 4-parameter Compressible Packing Model (CPM) including a new theory about wall effect and loosening effect for spheres", *Powder Technology*, vol. 302, no. 1, pp. 247-253, 2016.

[6] A.V. Usherov-Marshak, "*Dobavki v beton: progress i problemy*", Stroitel'nye materialy, no.1, pp. 8-12, 2006.

[7] R.F. Runova, V.I. Goc, M.A. Sanic'kij ta in., *Konstrukcijni materiali novogo pokolinnya ta tekhnologiï ïh vprovadzhennya v budivnictvo*. K: UVPK «EksOb», 2008.

[8] T. Kropyvnitska, M. Sanytsky, T. Rucinska, O. Rykhlitska, "Development of nanomodified rapid hardening clicker – efficient concretes based on Portland-composite cement", *Eastern-European Journal of Enterprise Technologies. Technology organic and inorganic substances*, vol. 4/6(100), pp. 38-48, 2019.

[9] I.V. Barabash, *Mekhanohimichna aktivaciya mineral'nih v'yazhuchih rechovin*. Odesa, AstroprInt, 2002.

[10] V.N. Vyrovoj, I.V. Barabash, A.V. Dorofeev, I.N. Babij, T.I. Barabash, V.D. Matkovskij, S.E. Gurevich, *Mekhanoaktivaciya v tekhnologii betonov*. Odessa: OGASA, 2014.

[11] I. Barabash, D. Harashenko, "Mechanoactivation of the Portland cement in technology of manufacturing self-compacting concrete", Eastern-European journal of enterprise technologies, no. 3/6 (93), pp. 12-17, 2018.

[12] A.I. Adyilhodzhaev, V.I. Solomatov, *Osnovyi intensivnoy razdelnoy tehnologii betona*. Tashkent: Fan, 1983.

[13] A.V. Smolyarov, "Vliyaniye tsementa s mineralnymi dobavkami iz molotogo prirodnogo peska i granitnogo otseva na svoystva tyazhelogo betona", *Sb. nauch. tr*. Minsk: NIIS, 2019, Vyp. II, pp. 271-287.

ІНТЕНСИВНА РОЗДІЛЬНА ТЕХНОЛОГІЯ І ЇЇ ВПЛИВ НА ВЛАСТИВОСТІ ЦЕМЕНТНО-ВОДНИХ КОМПОЗИЦІЙ, РОЗЧИНІВ ТА БЕТОНІВ НА ЇХ ОСНОВІ

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Анотація. У статті розглянуті питання щодо механоактивації портландцементу у роздільній технології виготовлення бетонних сумішей при виробництві бетонних та залізобетонних виробів. Зазвичай, важливою характеристикою композиційних будівельних матеріалів на основі портландцементу та його різновидів, що використовуються в будівництві, є їх швидкий набір міцності. Тому актуальними є наукові дослідження, які пов'язані з розробкою технологій, спрямованих на інтенсифікацію процесів гідратації цементу та зростання швидкості набору міцності бетону. В роботі наведені основні технологічні процеси при виробництві бетонних сумішей за інтенсивною роздільною технологією. Застосування даної технології, зокрема, дозволяє суттєво підвищити оборотність форм за рахунок більш інтенсивного набору міцності бетоном на механоактивованому портландцементі, особливо у ранні терміни твердіння. Обґрунтована необхідність введення під час приготування цементно-водної композиції в швидкісному змішувачі мінерального наповнювача у вигляді молотого кварцового піску. Експериментально встановлено, що швидкісне змішування цементно-водної композиції в присутності суперпластифікатора С-3 викликає різке зниження її ефективної в’язкості, що позитивно позначається на зниженні водовмісту бетонних сумішей необхідної легкоукладальності. Механоактивація портландцементу викликає зростання кількості хімічно зв'язаної води в цементному камені марочного віку з 13,1% до 17.9%, тобто більше ніж на 36% в порівнянні з контролем. Встановлено, що при однаковій витраті в'яжучого, міцність бетону на активованому портландцементу на першу добу тверднення в 1,8…2 рази вища у порівнянні з бетоном аналогічного складу, в'яжуче якого активації не піддавалося. З плином часу вплив активації на міцність бетону дещо знижується, але і у 28-и добовому віці міцність бетону на стиск на активованому в'яжучому в середньому на 25…30% вища у порівнянні з контролем.

Ключові слова: бетон, роздільна технологія, трибоактиватор, наповнювач, механоактивація.

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