У статті показано можливість одержання самоущільнювальних бетонів, що містять велику кількість додаткових цементуючих матеріалів, зокрема золи винесення. Приведено результати досліджень реологічних властивостей фіброармованих самоущільнювальних бетонних сумішей з високим вмістом золи винесення та добавками, що регулюють текучість та в'язкість бетонних сумішей. Встановлено, що заміна 55, 70 та 85 мас. % в'яжучого золою винесення дозволяє одержувати самоущільнювальні бетонні суміші з класом за розпливом конуса SF2, умовною в'язкістю T500=5 с та повітрозахопленням 0,4 %

Ключові слова: самоущільнювальний бетон, базальтова фібра, зола винесення, міцність, стиранiсть, модуль пружності, коефіцієнт Пуассона

В статье показана возможность получения самоуплотненных бетонов, содержащих большое количество дополнительных цементирующих материалов, в частности золы вынесения. Приведены результаты исследований реологических свойств фиброармованых самоуплотненных бетонных смесей с высоким содержанием золы уноса и добавками, регулирующих текучесть и вязкость бетонных смесей. Установлено, что замена 55, 70 и 85 масс. % вяжущего золой вынесения позволяет получать самоуплотненные бетонные смеси с классом за расплывом конуса SF2, условной вязкостью T500=5 с и воздухововлечением 0,4 %

Ключевые слова: самоуплотненный бетон, базальтовая фибра, зола вынесения, прочность, истираемость, модуль упругости, коэффициент Пуассона

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DURABILITY PROPERTIES OF HIGH VOLUME FLY ASH SELF-COMPACTING FIBER REINFORCED CONCRETES

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1. Introduction

One of the main tasks of modern construction is reference project in harmony with nature and compliance with the concept of sustainable development using highly-environmentally friendly material. In the context of concrete that is most applicable building material, less expensive cement substitutes must be determined.

In recent years, much research on using additional supplementary cementitious materials (SCM), such as fly ash, blast furnace slag, microsilica, metakaolin et al., were to improve the properties of concrete and reduce construction costs [1]. One of the areas of innovative concrete technology is the technology of self compacting concrete (SCC). The use of this material eliminates the concrete vibration, which in turn reduces energy consumption and saves time, improving sanitary conditions.

2. Analysis of published data and problem statement

Fundamental elements of concrete environmental technologies for the environment support in accordance with sustainable development strategy are primary materials maintenance, durability increase of concrete structures and technology holistic approach [2]. Self compacting concrete is an innovative material that is able to thicken under its own weight, completely filling the form even in high-density reinforcement structures, with simultaneous workability maintaining and capacity for spontaneous release of air pockets trapped during concrete mixing. Self compacting concrete contains a large number of supplementary cementitious materials, superplasticizer and viscosity additives. The characteristics of this concrete (large content of cement paste and mineral additives, the ratio of coarse and fine aggregate close to 1) are related to the terms of its placement, which can change its mechanical behavior. The use of mineral additives such as fly ash can result in deformations increase of setting shrinkage [3, 4]. Based on the above mentioned information it is relevant to research the fly ash impact as the supplementary cementitious material and fibers on self compacting concrete mixes properties and concretes on their basis. The use of this composite will allow to successfully to provide placement of industrial concrete floors and others.

During new concrete recipes developing except the classic requirements to the concrete durability and energy consumption on its production become more and more important. Thus for preventing of ecological balance, Portland cement clinker content in the composition of the concrete mix plays the crucial role. There is an increased demands on the fluidity and the self compacting possibility of modern concretes, that's why fine filler should be used as a part of the concrete mix. In this case the special attention should be paid to fly ash which is a by-product now [5].

Fly ash is mainly used in concrete ranging from 15 to 25 % of total cementitious material, although its content can vary depending on the fly ash properties and application conditions of concrete. With high content of fly ash slowdown of early strength set and delay of the construction speed are observed. For each case the optimal amount of fly ash which can be used in concrete mix and can provide the most technological, environmental and economic advantages from its usage without significant impact on the construction speed and reduction of the constructions durability [3] are determined.

Technology of self compacting concrete allows faster and safer give a shape of construction projects compared to concrete using with common properties. In the case of self compacting concrete giving a shape of concrete elements is performed much easier and the end result extends flexibility during the hardened concrete using. One of the modifications of such composite is an adding of different fibers like dispersed reinforcement in the concrete mix, that allows to increase the strength of the cement matrix on bending down, its crack resistance, impact strength and ensures its reliable operation [5].

Mechanical properties of cement fiber reinforced composite are the result of synergistic interaction between the concrete matrix properties and the effect of their strengthening that provides dispersed reinforcement. This strengthening effect depends on the size, geometry and dosage of fibers, their strength, distribution and orientation according to the applied load and fiber-matrix connections [6]. Schematic representation of fiber reinforced concrete structure is shown in Fig. 1.

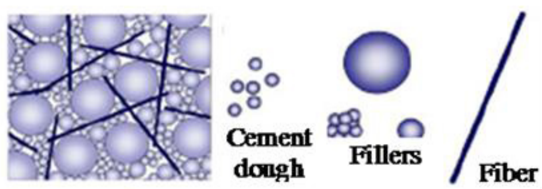

Fig. 1. Fiber reinforced concrete structure

The sharp prices rise for traditional steel reinforcement in the international markets, causes the necessity of decisions search that would limit the steel use. Fiber can effectively replace the reinforcing into rod reinforcement in plate constructions of industrial floors, roads and bending elements. Market analysts point to a significant increase in steel consumption in China and India as an important factor in the prices growth for steel products in the international markets. An important argument for the use of synthetic dispersed reinforcement is simplicity of its use.

Nowadays constraints in the process of concrete products reinforcement of glass, polymer and metal fibers are low chemical resistance of these fibers in a hardened cement paste, the high cost of synthetic fibers with their low efficiency, the shortage of metal fiber. All these mentioned above lacks are completely absent in basalt fiber. During reinforced concrete use special attention is paid to composition materials, in which cement stone based on Portland cement performs the role of matrix, and basalt fibers are used as reinforcement. Using basalt fiber allows in large part to compensate the main lacks of concrete such as: lower tensile strength and impact strength. During using of basalt fibers frost resistance, heat resistance, abrasion resistance and moisture resistance are increased, three-dimensional reinforcement is provided, shrinkage deformations are reduced, fracture toughness, impact strength are significantly increased, etc. [7, 8].

3. Purpose and objectives of the study

The aim of this research is to develop fiber reinforced self compacting concrete with basalt fiber and high volume fly ash and to investigate technological properties of concrete and operational characteristics of hardened concrete.

In accordance with the set goal the following research objectives are identified:

1. Investigate the flowability and viscosity of high volume fly ash self compacting fiber reinforced concretes.
2. Detail study of tests on self compacting concrete samples abrasion.
3. Observe dependence between stresses and deformations in the self compacting concretes with high volume fly ash.

4. Research methods and materials characteristics

To prepare fiber reinforced self compacting concrete during experimental research, Portland cement CEM II/A-S-42,5N production of "Volyn-cement" with the following characteristics: specific surface S_p=395 m^2/kg, the sieve residue № 008 – 1.2 mass. %, start hardening – 2 hours 30 minutes, the end – 4 hours 00 minutes, the border compressive strength after 2; 7 and 28 days – 18.5; 29.1 and 52.5 MPa respectively is used.

Basalt fiber RBR-18-T10/24 LLC "Tehnobazalt-Invest" (Kyiv), fiber length 24 mm, diameter 18 mm, made of basalt roving for TU V.2.7-26.8-34323267-002:2009 which will provide three-dimensional reinforcement that provides a mix served as reinforcing element.

As fine aggregate for self compacting concrete, quartz sand deposits of the Zhovkiv field Lviv region and granite fraction 2–5 mm are used. Gravel fractions 5–20 mm with bulk density – 1480 kg/m^3, void ratio – 43.5 %, true density – 2.62 g/cm^3, crushing capacity D_r=8 % served as coarse aggregate for making concrete.

As an additional cementing material, fly ash from Burshtyn TPP with the following properties: true density – 2.21 g/cm^3, bulk density – 870 kg/m^3, remainder on sieve № 008 – 8,7 masses. %, chemical composition, mass. %: SiO_2 – 54; Al_2O_3 – 23.75; Fe_2O_3+FeO – 13,8; MgO – 1,91; CaO – 4,98; SO_3 – 0.53; K_2O+Na_2O – 0,25 is used.

In order to provide high performance concrete mix mobility, superplasticizer based on polycarboxylate Basf Glenium ACE 430 (PC) was injected to their composition.

Technological and building-technical properties of fiber reinforced self compacting concrete was determined by special methods of assessing their quality of existing standards and generally accepted methods.

5. Test results and discussion of high volume fly ash self compacting fiber reinforced concretes

Research impact of the imposition of fly ashes was carried out on self compacting concrete, composition of which is represented by a weight ratio of components of 1:1,1:2,2, W/B=0,32, total consumption of binder per 1 m^3 of concrete was 520 kg. When conducting the research, fly ash as part of total cementitious material took 55, 70 and 85 mass. %. The results of the impact of the imposition of fly ashes and basalt fiber to a self compacting concrete features are presented in Table 1.

Table 1

The impact of the imposition of fly ashes on the properties of self compacting concrete

Fly ash content, mass. %	Fiber content, %	Flowability, mm	Viscosity, T_{500}, s	Air entraining, %
55	–	720	5.0	0.4
70	–	700	5.0	0.4
85	–	680	6.0	0.4
55	0.5	730	6.0	0.35
70	0.5	700	5.5	0.35
85	0.5	730	5.5	0.4

As can be seen from the Table 1, flowability of self compacting concrete with the addition of fly ash is 680–720 mm, the introduction of 0.5 % basalt fiber has virtually no effect on the change in the flowability of self compacting concrete. Such self compacting concrete mix flowability can be classified as SF2. In addition to high yield point, the mix should have sufficient viscosity to prevent segregation. In the language viscosity of self compacting concrete mix were evaluated over time to flowability of the spreading cone of 500 mm (T_{500}). Viscosity of self compacting concrete with different contents of fly ash and basalt fiber within 5–6 seconds that meets self compacting concrete mixes can be attributed to such class of conditional viscosity VS2 ($T2 \geq_{500}$s). It should be noted that the introduction of basalt fiber does not cause a significant change in the air entraining of concrete, average density of obtained self compacting concrete is within 2320–2340 kg/m^3.

Substitution of 55 mass. % cement by fly ash allows a self compacting concrete strength of 38,7 MPa after 28 days of curing in normal conditions, the introduction of 0,5 % basalt fiber provides increasing strength of the concrete to 41.8 MPa (ΔR=10,8 %) (Fig. 2). For concrete containing 85 mass. % fly ash after 28 days of curing in normal strength is 15,0 MPa, putting 0,5 % basalt fiber provides strength increase to 25,4 MPa (ΔR=69 %).

Definition diligence was carried out in accordance with DSTU B V.2.7-212:2009 "Building materials. Concrete". Methods for determining abrasion on wheel abrasion LCI-3. Weighing scales samples carried out by technical Radwag WLC 20/C/1.

It was made for self compacting concrete samples with dimensions of 70x70x70 mm in accordance with DSTU B V.2.7-212:2009 in the number of 27 pieces for the content test to determine abrasion capacity to determine the impact of the introduction of basalt fiber in the concrete mix to concrete containing fiber 0; 0,5 and 1 % by weight of cement in the dry state and determine the effect of fly ash content in the binder took 55, 70 and 85 mass. % respectively.

9 series and 3 samples in each series: 3 series of fiber containing 0; 0.5 and 1 % by weight of dry cement and 3 series of content of fly ash binder took 55, 70 and 85 mass. %, respectively were tested. The test results are shown in Table 2.

Table 2

The results of tests on concrete samples abrasion

N p/p	Fly ash content, mass. %	Fiber content, %	The dimensions of the abrasive surface, cm	The surface area of the abrasive surface, cm^2	Mass of sample, g		Abrasion sample, g/cm^2	Abrasion resistance, g/cm^2
					before abrasion	after abrasion		
1	55	0	7,08x7,12	50,41	829,0	810,2	0,37	0,35
			7,08x7,09	50,20	844,7	827,4	0,34	
			7,03x7,07	49,70	835,8	818,7	0,34	
2		0,5	7,02x7,03	49,35	801,3	787,6	0,28	0,28
			7,12x7,10	50,55	818,2	802,1	0,32	
			7,05x7,08	49,91	820,8	807,8	0,26	
3		1	7,05x7,05	49,7	812,9	801,4	0,23	0,23
			7,09x7,07	50,13	813,7	802,2	0,23	
			7,03x7,05	49,84	815,4	803,6	0,24	
4	70	0	7,04x7,05	49,63	828,3	810,6	0,36	0,35
			7,04x7,05	49,63	825,6	808,9	0,34	
			7,06x7,07	49,91	822,2	804,7	0,35	
5		0,5	7,03x7,07	49,70	814,3	790,1	0,30	0,30
			7,12x7,10	50,55	806,7	799,6	0,33	
			7,06x7,06	49,84	819,8	805,9	0,28	
6		1	7,09x7,09	50,27	799,0	785,6	0,26	0,26
			7,07x7,07	49,98	807,2	794,3	0,26	
			7,02x7,03	49,35	812,8	799,3	0,27	
7	85 %	0	7,02x7,03	49,35	801,1	784,9	0,33	0,36
			7,02x7,03	49,35	788,6	770,9	0,36	
			7,06x7,06	49,84	809,8	792,0	0,36	
8		0,5	7,12x7,10	50,55	784,2	767,2	0,33	0,31
			7,02x7,02	49,28	822,7	809,3	0,28	
			7,07x7,07	49,98	819,5	803,5	0,32	
9		1	7,02x7,02	49,28	800,1	785,4	0,30	0,30
			7,02x7,02	49,28	800,3	785,6	0,30	
			7,06x7,06	49,84	805,8	790,8	0,30	

Elevated levels of mortar, typical for self compacting concretes determines their increased deformability. Traditionally cast concrete mixs are characterized by lower elastic modulus values, higher values of Poisson's ratio, longitudinal and transverse strain compared to self compacting concretes. Strain and physical and mechanical characteristics were determined by testing six series of prisms and cubes 100×100×400 mm 100×100×100 mm of self compacting concrete containing fly ash 55, 70 and 85 mass. % without fiber and containing basalt fiber 0,5 and 1 % after 90 days of curing in normal conditions to the range of 0.6 ~R_p (R_p – breaking load). As the results of studies, self compacting prism strength of concrete at 90 days cube makers reaches 80–90 % (Table 3). Determination of elastic modulus and Poisson's ratio of concrete was held at the level of load of 30 % of the breaking strength (σ=0,3P_p/S).

Table 3

Indicators of deformability of self compacting concrete (After 90 days of curing samples in normal conditions)

Fly ash content, mass. %	Fiber content, %	Prism strength, $f_{ck, prism}$, MPa	Cube strength, $f_{cm, cube}$, MPa	The elastic modulus, E_{cm}, GPa	Poisson's ratio, ν
55	–	42,9	51,1	35,7	0,20
70	–	30,8	33,4	32,5	0,21
85	–	20,0	23,8	22,8	0,22
55	0,5	43,5	53,8	38,6	0,19
70	0,5	31,5	34,5	35,7	0,14
85	0,5	21,0	28,3	23,0	0,14

Research of deformation properties of self compacting concrete evidence that prism strength of concrete containing fly ash 55, 70 and 85 mass. % is respectively 42,9, 30,8 and 20,0 MPa, whereas the introduction of basalt fiber 0.5 %, increases it to 43,5, 31,5 and 21,0 MPa respectively. Modulus of self compacting concrete containing fly ash 55, 70 and 85 mass. % at introduction of 0.5 % basalt fiber increases from 35,7, 32,5 22,8 to 38,6, 35,7, 23,0 GPa, respectively, and decreases Poisson's ratio from 0.20, 0.21, 0.22 and 0.19, 0.14 respectively.

Fig. 3 shows the dependence of axial and transverse concrete strains on the applied load after 90 days of curing in normal conditions. Self compacting concrete with high volume fly ash content without fiber is characterized by elevated deformations under load compared to self compacting concrete with the addition of basalt fibers. It is known [6], the use of basalt fiber improves mechanical properties of self compacting concrete. Investigation of basalt fiber on properties of self compacting fiber reinforced concrete with high volume fly ash content established that disperse reinforcing of the growth of strained σ at a constant value of relative deformations and ε. Thus, the replacement of 55 mass. % fly ash cement making and administration of 0,5 % basalt fiber at the relative deformations and $\varepsilon=10...50\cdot10^{-5}$ provided increased stress σ on 7,3–10,1 % compared with concrete without fiber. For self compacting concrete containing 70 mass. % fly ash making, the figure is within 0,9–5,6 %. When replacing 85 mass. % of cement fly ash when administered 0,5 % increase basalt fiber stresses by 4,5–13,1 % is a value of relative deformations is $\varepsilon=10...35\cdot10^{-5}$.

Charts can be identified by straight sections, indicating the concrete work in elastic stage. With the increasing burden in developing concrete, plastic deformation is characterized by curvilinear dependence on the charts. Thus, the growth of basalt fiber internal pressure at constant strain of self compacting concrete with high volume fly ash.

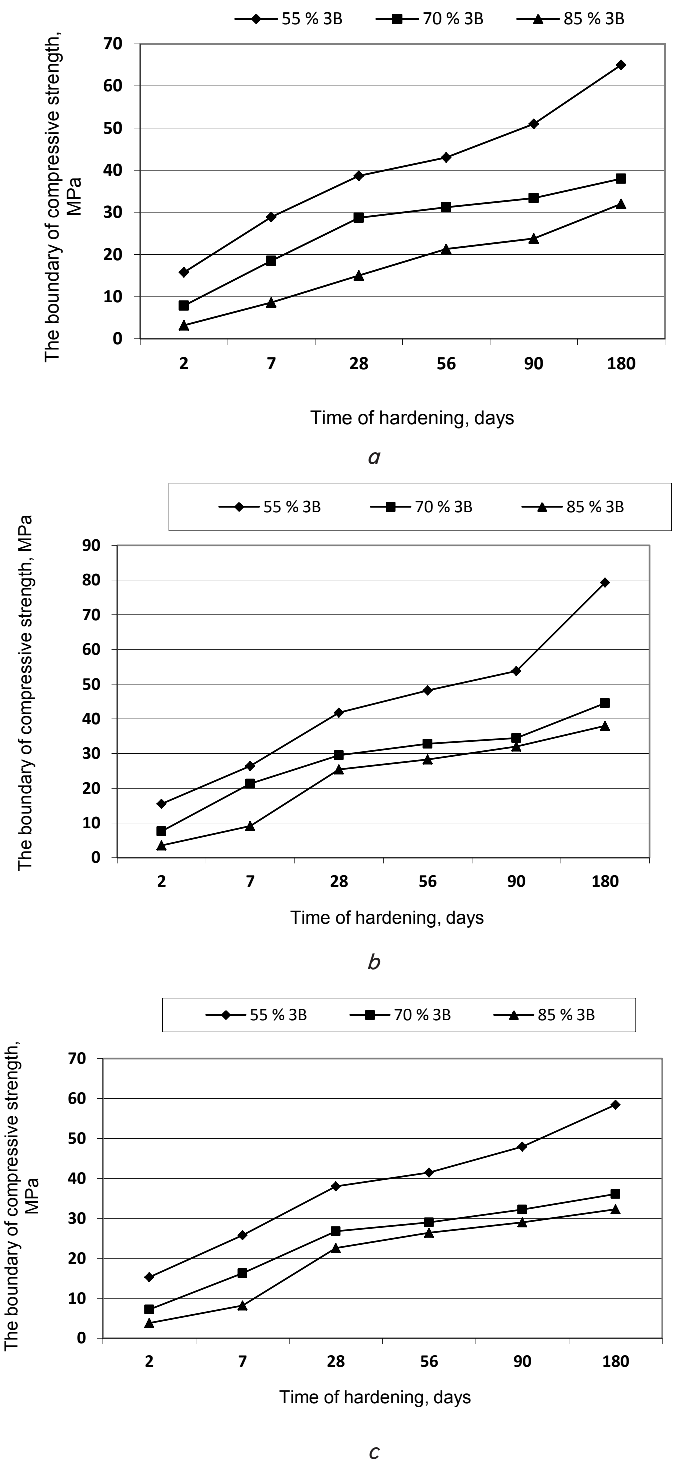

Fig. 2. Strength of self compacting concrete with high volume fly ash: *a* – no fiber; *b* – with 0,5 % basalt fiber; *c* – with 1 % basalt fiber

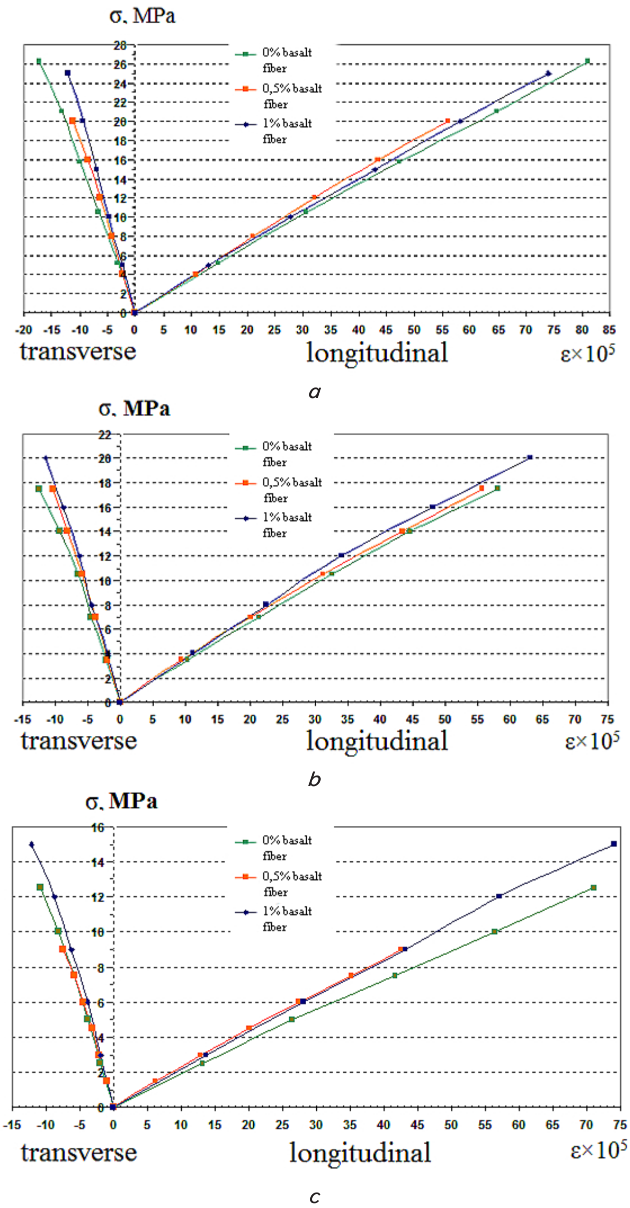

Fig. 3. Chart of dependence between stresses and deformations in the self compacting concretes with fly ash: *a* — 55 mass. %; *b* — 70 mass. %; *c* — 85 mass. %

6. Conclusion

Research of rheological properties of self compacting concrete mixes with high volume fly ash content found that the replacement of 55, 70 and 85 mass. % binder fly ash allows to obtain concrete mixes with a class for slump flow SF2 (slump flow 600–730 mm), viscosity T_{500}=5 s (Class for Viscosity VS2) and air entraining 0,4 %. With an amine 55 mass. % fly ash cement making and administration of 0,5 % basalt fiber allows a self compacting concrete strength of 41.8 MPa after 28 days of curing in normal conditions, and concrete containing 85 mass. % fly ash as part of a binder is characterized by strength 25.4 MPa. Self compacting fiber reinforced concrete with high volume fly ash content and basalt fibers ensure sustainable growth of stresses and relative deformation compared with self compacting concrete without addition of basalt fiber. Developed fiber reinforcing self compacting concrete with high volume fly ash content can be used in industrial floors, which will receive high-quality surface with lower energy costs. Abrasion resistance of self compacting concrete with basalt fiber decreased by 14.3 % while the content of 85 mass. %. fly ash as part of binder compared with concrete without fiber. This replacement of 70 mass. % of cement fly ash to reduce friction with the introduction of basalt fiber 1 % to 25.7 %. For concrete containing 55 mass. % fly ash, abrasion resistance is 0.35 g/cm^2, the introduction of 0.5 % basalt fiber decreases abrasion to 0.31 g/cm^2 (Δ=11,4 %); when administered 1 % basalt fiber friction is reduced to 0.23 g/cm^2 (Δ=34,3 %)

References

1. Szwabowski, J. Technologia betonu samozageszczalnego [Text] / J. Szwabowski, J. Golaszewski. Krakov: Stowarzyszenie Producentov Cementu, 2010. – 160 p.
2. Dinakar, P. Durability properties of high volume fly ash self compacting concretes [Text] / P. Dinakar, K. G. Babu, M. Santhanam // Cement & Concrete Composites. – 2008. – Vol. 30. – P. 880–886. doi: 10.1016/j.cemcodcomp.2008.06.011
3. Thomas, M. Optimizing the Use of Fly Ash in Concrete [Text] / M. Thomas // Portland Cement Association – 2014. – Vol. 2. – P. 1–24.
4. Koval', S. V. Puti sozdanija samouplotnjajushhihsja betonov [Text]: mizhvid. nauk.-tehn. zb. / S. V. Koval', D. M. Poljakov, M. Sitarski, M. Ciak // Budivel'ni konstrukcii. – 2009. – Vol. 72. – P. 232–238.
5. Poljakov, D. M. Samouplotnjajushhijsja beton s karbonatnym napolnitelem [Tekst]: avtoref. diss. ... kand. tehn. nauk / D. M. Poljakov. – Odessa: OGASA, 2010. – 17 s.
6. Khayat, K. Mechanical Properties of Self-Compacting Concrete: State-of-the-Art Report of the RILEM Technical Committee 228-MPS on Mechanical Properties of Self-Compacting Concrete [Text] / K. Khayat, G. De Schutter. – Springer Science & Business Media, 2014. – 290 p.
7. Corinaldesi, V. Durable fiber reinforced self-compacting concrete [Text] / V. Corinaldesi, G. Moriconi // Cement and Concrete Research. – 2004. – Vol. 34, Issue 2. – P. 249–254. doi: 10.1016/j.cemconres.2003.07.005
8. Ghanbari, A. Prediction of the plastic viscosity of self-compacting steel fibre reinforced concrete [Text] / A. Ghanbari, B. L. Karihaloo // Cement and Concrete Research. – 2009. – Vol. 39, Issue 12. – P. 1209–1216. doi: 10.1016/j.cemconres.2009.08.018
9. Poznyak, O. R. Properties of self-compacting concrete with basalt fiber [Text] / O. R. Poznyak, I. I. Kirakevych, M. S. Stechyshyn // Visnyk Nacional'nogo universytetu "L'vivs'ka politehnika". "Teorija i praktyka budivnyctva". – 2014. – Vol. 781. – P. 149–153.
10. Ponikievskij, T. Reologicheskie svojstva svezhego samouplotnjajushhegosja betona, armirovannogo stal'nym voloknom [Text] / T. Ponikievskij // Mezhdunarodnoe betonnoe proizvodstvo. – 2010. – Vol. 5. – P. 42-50.