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SELF-COMPACTING CONCRETES WITH THE POLYMER ADMIXTURE

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ABSTRACT

The research results of properties of self-compacting fine-grained ash-cement mixes and concretes containing the polyfunctional modifier are presented. With the optimal composition of such a modifier, which includes polyvinyl acetate dispersion and superplasticizer, it becomes possible to improve self-compacting concrete's properties significantly.

Keywords: self-compacting concrete, polyfunctional modifier, polyvinyl acetate dispersion, water absorption, water separation, abrasion.

INTRODUCTION

Low deformability of concrete, and especially its tensile strength is one of the main reasons for lack of crack resistance. Increasing the tensile strength of cement concretes and mortars and their deformability is one of the main consequences of the use of polymer admixtures in cement systems [1 - 8].

Studies have shown that at 10 % admixture of polyvinyl acetate dispersion (PVAD) the flexural tensile strength of cement-sand mortar (1 : 3) under combined hardening conditions exceeded 3 - 4 times the strength of control specimens, and when hardening in the air - 2.9 times [1]. A positive effect on flexural tensile strength and on the compressive strength/flexural tensile strength ratio (f_{cm} / $f_{c,tf}$ ratio) is also observed when latex and water-soluble resins are added to cement mortars [8].

For cement concretes and mortars as floor materials, significant consequence of the introduction of polymer admixtures is the increase in their impact strength, adhesion, and wear resistance [9, 10]. According to M. Brocard, polyvinyl acetate concrete, which hardened in conditions of 50 % humidity at a polymer-cement ratio (P/C) of 0.05 has 3 times greater resistance to abrasion than ordinary concrete [11]. At P/C = 0.1 and P/C = 0.2, this property increases by 12 and 20 times, respectively. For air-cured concretes with high P/C, the compressive strength and toughness of the specimens are significantly increased.

The positive effect of polymer admixtures on the porous system of cement stone causes their reduced permeability. Concrete containing polyvinyl acetate (PVA) shows less permeability and greater stability when saturated with non-polar liquids. This conclusion is valid in relation to the resistance of modified concretes and mortars to the aggressive action of various chemicals [12].

Reduction of porosity and filling of pores with polymers, as well as entrained air leads, as noted by most researchers, to increase the frost resistance of concrete and mortar. Ohama presented the study results of the specimens stability of modified mortars after 10 years of exposure to the environment in Tokyo [13]. Unlike specimens from the unmodified mortar, which were destroyed a year after being in normal conditions, most specimens from the modified mortar after 10 years have a satisfactory state under the same conditions. Ohama also notes that most of the modified mortars have good resistance to atmospheric CO_2 carbonization, which helps to prevent corrosion of steel reinforcement [2]. Modifying the properties of hardened concretes and mortars, polymer admixtures significantly affect the rheological and technological properties of cement mixtures. At low polymer-cement ratios, water-dispersed and water-soluble polymers, as a rule, have a plasticizing and air-entraining effect [10]. Modified cement mixtures differ favorably from conventional ones with increased water holding capacity, which increases with enlarging the polymer-cement ratio [13]. Relatively small amounts of polymers (2 - 3 %) allow to reduce microdefects in the structure of cement stone and concrete, to increase the homogeneity of concrete and to modify the structure of cement stone [14].

In recent decades, self-compacting concrete mixtures are increasingly being introduced into construction practice. They are especially effective for concreting thin-walled densely reinforced structures and installing self-leveling floors. Admixtures are especially effective for these mixtures, which, along with increasing plasticity and reducing water consumption, have a positive effect on water retention, loss of workability with time, and other construction and technical properties. Among such properties, those that determine the crack resistance of concrete are especially important.

Analysis of the available information on self-compacting fine-grained concrete (SCC) suggests that one of the effective ways to improve their technical properties is the use of polyfunctional modifiers (PM) containing superplasticizers and polymers. As for ash-cement self-compacting concrete, the effect of polymer admixtures cannot be considered sufficiently studied.

The aim of this research was to study the properties of self-compacting fine-grained ash-cement mixtures and concretes based on them with the use of PM, which designed for the installation of self-leveling floors.

EXPERIMENTAL

Portland cement class CEM I 42.5 R, fly ash with a specific surface area of 3100 $cm^2 g^{-1}$, and a mixture of quartz sand of two fractions 0.16 - 2 mm and 2 - 5 mm in the ratio of 0.8 : 0.2 with a fineness modulus of 2.1 are used. The consumption of binder (mix of cement and fly ash in the ratio of 0.7:0.3) was 575 kg m^{-3}. As a component of PM is used polyvinyl acetate dispersion (PVAD) - a water emulsion of thermoplastic polymer PVA. Polyfunctional modifier containing superplasticizer (SP) and PVAD was added to the concrete mix together with mixing water. Modified polycarboxylate ether Melflux 2651f was used as a superplasticizer.

Water consumption was brought to the flow of fine-grained concrete mixture 550 - 600 mm (class SF1 according to EN 12350-8). With such flow, as previous experiments have shown, the concrete cone slump is 26 - 27 cm.

Water separation of fresh concrete mixtures was determined after settling in a cylindrical vessel according to the EN 12350 method. The air content of self-compacting mixtures was determined by the volumetric method [15]. The loss of mixtures workability was determined by immersion of the flow cone at sand-bind ratio 2.5, W/C = 0.6 at a temperature of 20 ± 2°C.

To study the properties of self-compacting concrete specimens were made prisms 4´4´16 cm to determine compressive strength, flexural tensile strength, and water absorption, as well as cube specimens with a size of 7.07 cm to determine the abrasion of concrete. The specimens were hardened for testing in humid air conditions at 20 ± 2° C.

The composition of concrete at each point of the matrix was calculated using the method described in [16]. Strength characteristics of concrete specimens were determined according to ASTM C78, water absorption - according to BS 1881 - 122, and abrasion - according to ASTM C 779. Experiments to determine the strength were performed on specimens at 7, 28 and 90 days.

RESULTS AND DISCUSSION

To study the influence of the content and composition of PM on the properties of self-compacting ash-cement concrete mixtures, algorithmic experiments were performed by the three-level three-factor plan B_3 [16]. Conditions for planning experiments are given in Table 1. The studied parameters were water consumption of the mixture, L m^{-3}, water separation, % and air content, %.

The analysis of the obtained regression equations (Table 2) shows a significant reduction in water consumption with a high content of superplasticizer Melflux 2651f in the PM (Fig. 1). The most significant effect of SP is already affected by its dosage of 0.5 % by the weight of the binder. The overall reduction of water consumption with an SP content of 3 % was about 30 %.

PVAD refers to relatively weak plasticizers within the studied polymer-cement ratios. At a dosage of 0.5 %, it causes an almost imperceptible reduction in water consumption, at a dosage of 3 %, it was about 7 %.

Table 1. Conditions for planning experiments.

No.	Factors	Coded	Levels of variation		
			-1	0	+1
1	PM content, % by weight of binder	X_1	0.5	1.75	3
2	SP content as a part of PM	X_2	0	0.5	1.0
3	Sand-binder ratio	X_3	2	3	4

Table 2. Regression equations of the properties of SCC mixtures.

No.	Quality	Regression equation
1	Water consumption, L m^{-3}	$WC = 183.3-16.3X_1-8.1X_2+30.2X_3+5.5X_1^2+ 5.5X_2^2+ +9.3X_3^2-6.9X_1X_2-7.3X_1X_3-6.7X_2X_3$ (1)
2	Water separation, %	$WS =1.14+0.13X_1+0.41X_2+0.34X_3-0.02X_1^2-0.20X_2^2- -0.02X_3^2+0.226X_1X_2+0.1X_1X_3$ (2)
3	Air content, %	$AC =1.9+0,13X_1-0.41X_2+0.31X_3-0.02X_1^2-0.280X_2^2+ +0.07X_3^2-0.21X_1X_2+0.096X_1X_3-0.08X_2X_3$ (3)

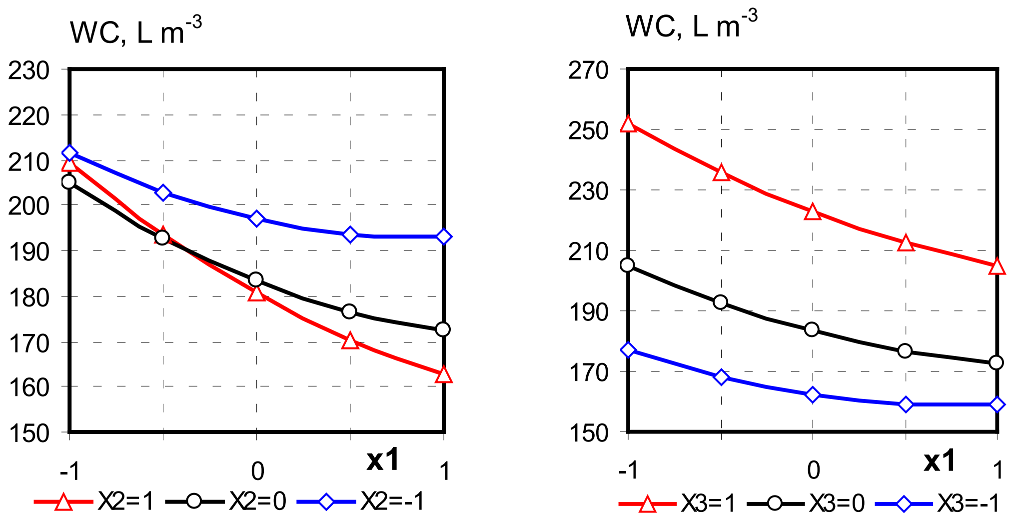

Fig. 1. Dependences of SCC water consumption on the studied factors.

Water consumption of concrete mixtures containing both components of PM is of average value, but with their same introduction by weight, it is lower than it follows from the additivity condition (Fig. 1).

There is conflicting data on the effect of superplasticizers on the water separation of concrete mixtures, including fine-grained. The tendency of such mixtures to stratification is noted. To our experimental data, when dosing SP up to 1 %, the water separation of SCC mixtures does not grow, and then tends to increase (Fig. 2). At the same time, PVAD provides a reduction of water separation in all ranges of dosages from 0.5 to 3 %. The presence of both components in PFM leads to the fact that their water separation is the same as without admixtures (Fig. 2). This can be explained mainly by the air-repellent ability of the investigated polymer additive. Increasing the content of PVAD from 0 to 3 % in self-compacting mixtures additionally draws in more than 1 % of air and as a result, the total air content increases to 2.5 % (Fig. 3). The calculated air content curves of SCC mixtures obtained based on the corresponding regression equations are shown in Fig. 3. They reflect the well-known conclusion that in flow concrete mixtures superplasticizers help to remove air [17, 18]. The joint introduction of SP and PVAD prevents the above negative effect.

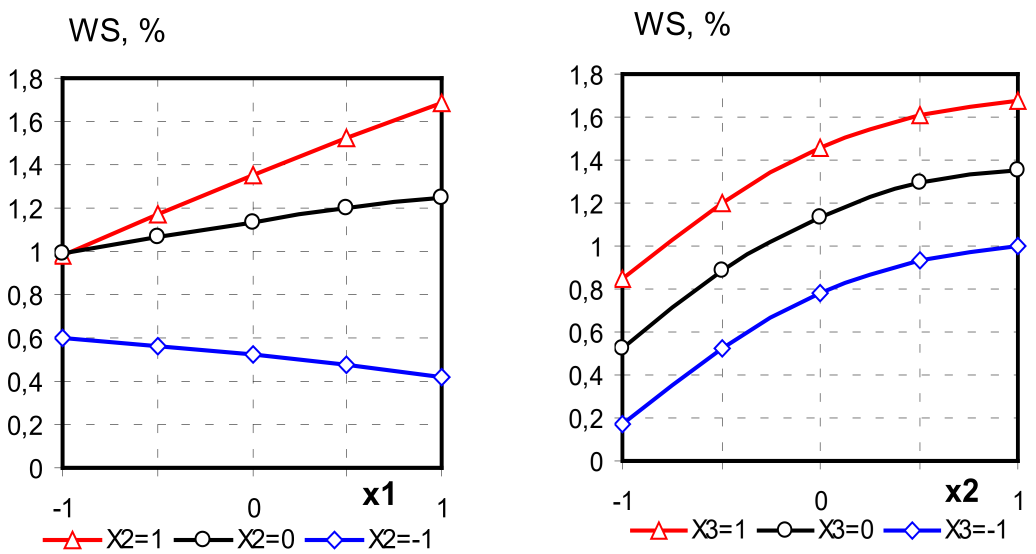

Fig. 2. Dependences of SCC water separation on the studied factors.

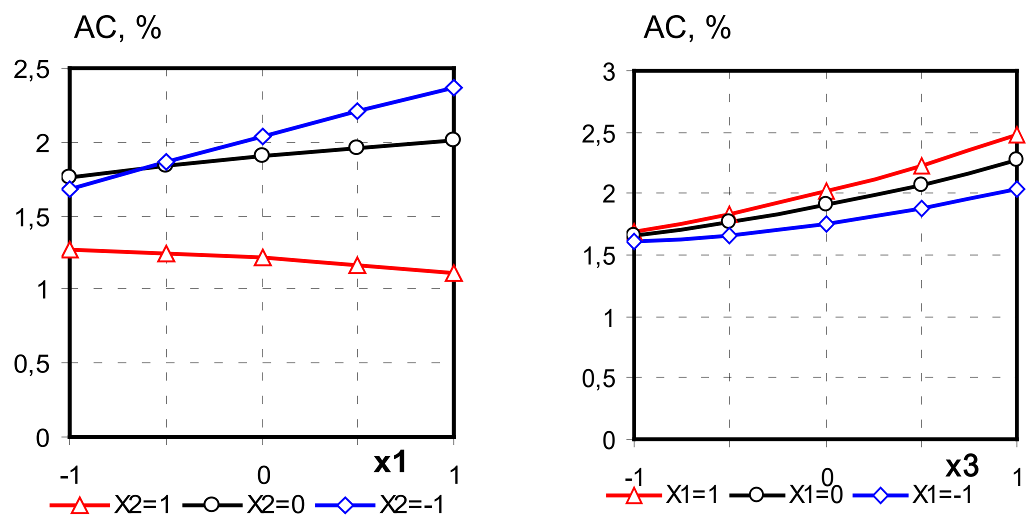

Fig. 3. Dependences of SCC air content on the studied factors.

Fresh concrete is well known to lose its workability with time. This phenomenon is called “slump loss”. For the studied SCC mixtures, the loss of workability was determined. The results of the experiments are presented in Fig. 4. The lowest rate of workability loss is typical for mixtures in which the PM is represented only by PVAD, and the highest one - is SP. Increasing the content of the admixture helps to stabilize the workability. The low value of the slump loss for mixtures with the addition of PVAD can be explained by its slowing effect on the hardening time of the cement paste and less intense kinetics of plastic strength growth.

The experiments according to the matrix of the three-level three-factor plan B_3 were carried out [16]. As a result of the experiments, the regression equations of compressive strength (f_{cm}) and flexural tensile strength ($f_{c,tf}$), as well as abrasion (A) and water absorption (W) at 28 days were obtained. The consumption of binder was 575 kg m^{-3}. The proportion of sand to binder in the experiments was n = 2.5. The conditions for planning the experiment are given in Table 3.

As a result of statistical processing, the obtained regression equations (mathematical models) of the SCC properties at 28 days are adequate at 95 % confidence and are given in the coded variables in Table 4.

For the compressive and flexural tensile strength

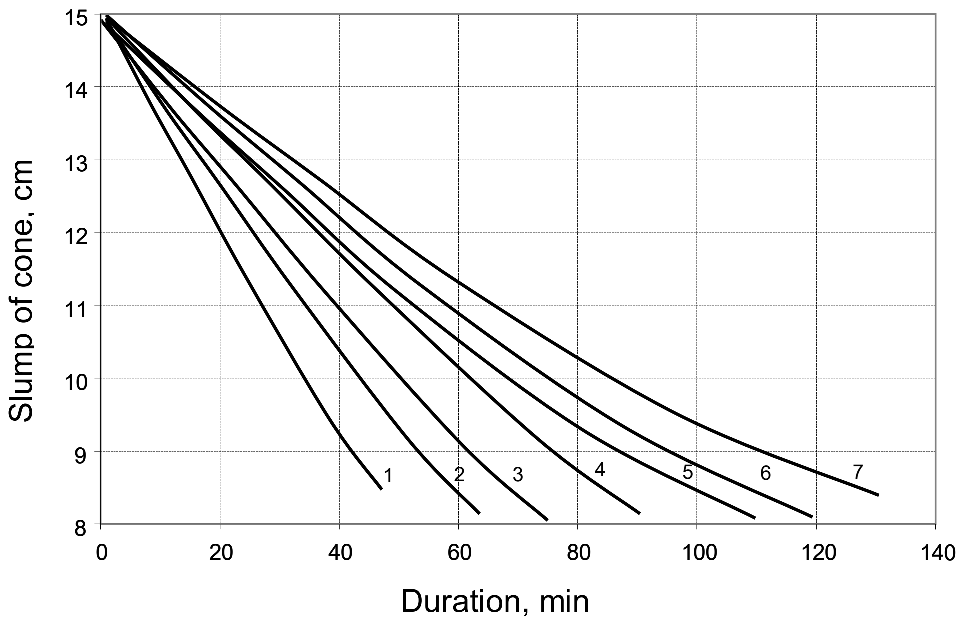

Fig. 4. The effect of PM additives on the loss of workability 1 – SP - 0.5 % by weight of cement; 2 – SP – 3 %; 3 – SP - 0.25 %; PVAD - 0.25 %; 4 – without additives; 5 – SP - 1.5 %; PVAD - 1.5 %; 6 – PVAD - 0.5 %; 7 – PVAD – 3 %.

Table 3. Conditions for planning experiments.

Factors	Coded	Levels of variation			Interval of variation
		-1	0	+1	
PM content,% by weight of binder	X_1	0.5	1.75	3	1.25
SP content as a part of PM	X_2	0	0.5	1.0	0.5
Water-binder ratio (W/B)	X_3	0.3	0.4	0.5	0.1

Table 4. Regression equations of the SCC properties.

No.	Output parameter	Regression equation
1	Compressive strength, MPa	$f_{cm} = 62.56+1.75X_1+6.12X_2-20.06X_3-1.946X_1^2-$ $-1.85X_2^2+5.2X_3^2+6.72X_1X_2-1{,}51X_1X_3$ (4)
2	Flexural tensile strength, MPa	$f_{c,tf} = 7.8+0.4X_1-0.23X_2-0.95X_3+0.09X_1^2-0.88X_2^2-$ $-0.44X_3^2+0.472X_1X_2$ (5)
3	Water absorption, %	$WA = 6.64-0.21X_1-0{,}57X_2+2.47X_3+0.15X_1^2+0.10X_2^2-$ $-0.20X_3^2-0.29X_1X_2$ (6)
4	Abrasion, g cm^{-2}	$A = 0.49-0.09X_1+0.08X_2+0.15X_3+0.06X_1^2+0.03X_2^2+$ $+0.04X_3^2+0.05X_1X_2+0.04X_2X_3$ (7)

(Fig. 5 and Fig. 6), the most significant of the studied factors was the water-binder ratio (X_3). It is noteworthy that for concretes with the addition of PM, as well as for conventional cement-sand mortars, the increase in W/C ratio leads to a much more significant decrease in compressive strength than the flexural tensile strength [19].

The increase in the content of PM (X_1) at W/B = const can contribute to either increasing or decreasing the compressive strength, depending on the composition of the complex admixture. In the case when the PM is

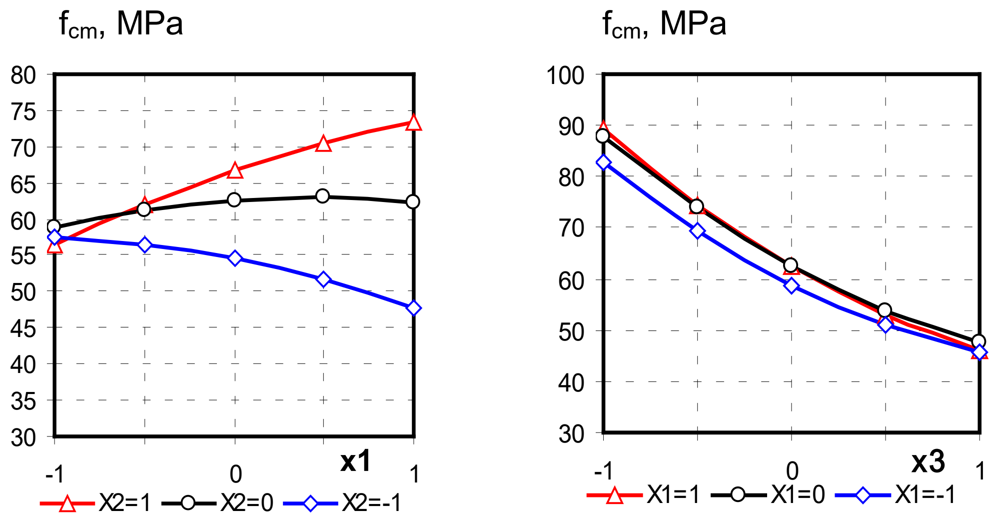

Fig. 5. Dependences of SCC compressive strength on the studied factors.

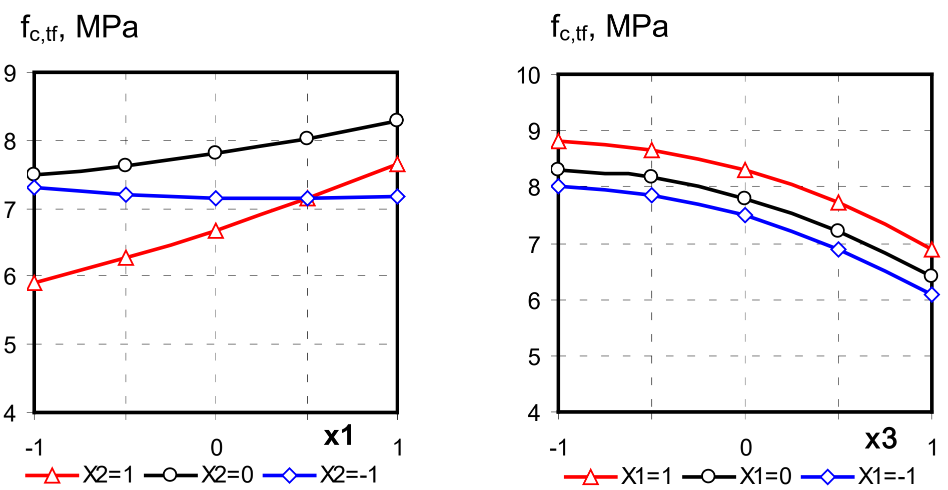

Fig. 6. Dependences of SCC flexural tensile strength on the studied factors.

represented only by the superplasticizer, increasing its content at a constant W/C ratio leads to a significant increase in strength.

Another nature of the effect on compressive strength of the second component of PM - PVAD. In the selected area of variation, an increase in its content, especially from 1.5 to 3 %, leads to a significant decrease in the compressive strength (Fig. 5). Slowing down the process of increasing the strength of polymer concretes has been observed by other researchers [8]. The influence of the studied PM on the flexural tensile strength (Fig. 6) has some features. In the studied range of PM dosages, the SCC flexural tensile strength increases most intensively in cases where the admixture is represented only by a superplasticizer. However, the absolute values of strength remain higher when using PM with a maximum content of SP, which is not more than 0.5 (Fig. 6). The obtained data show that in the area of low investigated concentrations of PVAD its noticeable positive effect on the SCC strength is noted. This effect increases in the area of high concentrations of polymer admixtures. Accordingly, the f_{cm} / $f_{c,tf}$ ratio decreases. Table 5 shows the calculated $f_{cm}/f_{c,tf}$ ratios of the SCC for various studied factors, obtained using the corresponding regression equations. The data in Table 5 show that the tendency to decrease $f_{cm}/f_{c,tf}$ is observed as the growth of both the total PM content and the increase in the polymer component content. The parameter $f_{cm}/f_{c,tf}$, in a certain

Table 5. Calculated f_{cm} / $f_{c,tf}$ ratios for SCC with PM additive.

No.	The natural values of factors			f_{cm} / $f_{c,tf}$		
	X_1	X_2	X_3	7 days	28 days	90 days
1	3	1	0.5	5.82	6.57	7.13
2	3	0	0.5	3.51	4.9	4.8
3	0.5	1	0.5	5.69	6.86	7.61
4	0.5	0	0.5	4.31	5.52	5.4
5	3	1	0.3	8.77	9.11	9.26
6	3	0	0.3	6.69	6.98	6.49
7	0.5	1	0.3	9.83	9.37	9.56
8	0.5	0	0.3	7.83	8.61	7.58

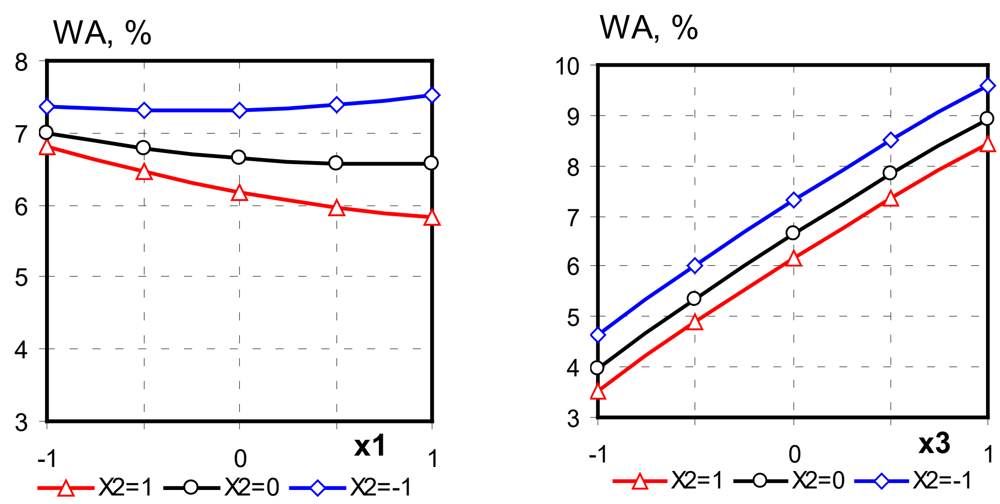

Fig. 7. Dependences of SCC water absorption on the studied factors.

way, characterizes the perfection of the composite material structure. It can be assumed that the lower $f_{cm}/f_{c,tf}$ ratio for SCC with PM is due to adsorption modification of the cement stone structure. SP, as well as polyvinyl acetate polymer, has adsorption capacity on the polar surfaces of hydrated compounds [20 - 22]. PVAD in sufficient quantities also forms a continuous membrane matrix, which contributes to the increased tensile and flexural strength of cement stone [14]. For concrete without admixtures and with a low content of PM, especially with the predominance of SP, there is a tendency to increase $f_{cm}/f_{c,tf}$ with the transition from early to later concrete age. With increasing content of PM and the polymer content, the ratio of strength parameters stabilizes over time, or there may even be a tendency to reduce $f_{cm}/f_{c,tf}$.

The change in water absorption of SCC with PM admixtures as their composition changes (Fig. 7) correlates well with the compressive strength. This can be explained by the close dependence of both properties on the open concrete porosity. With increasing W/B from 0.3 to 0.5, water absorption decreases almost linearly. In this case, concrete containing only superplasticizer as an admixture has the lowest water absorption. Increasing the content of SP in concrete from 0.5 to 3 % at W/B = 0.4 (X_3 = 0) allows to reduce, for example, water absorption from 8 to 6.5 %, i.e. by 18.7 %.

One of the most significant advantages of polymer-

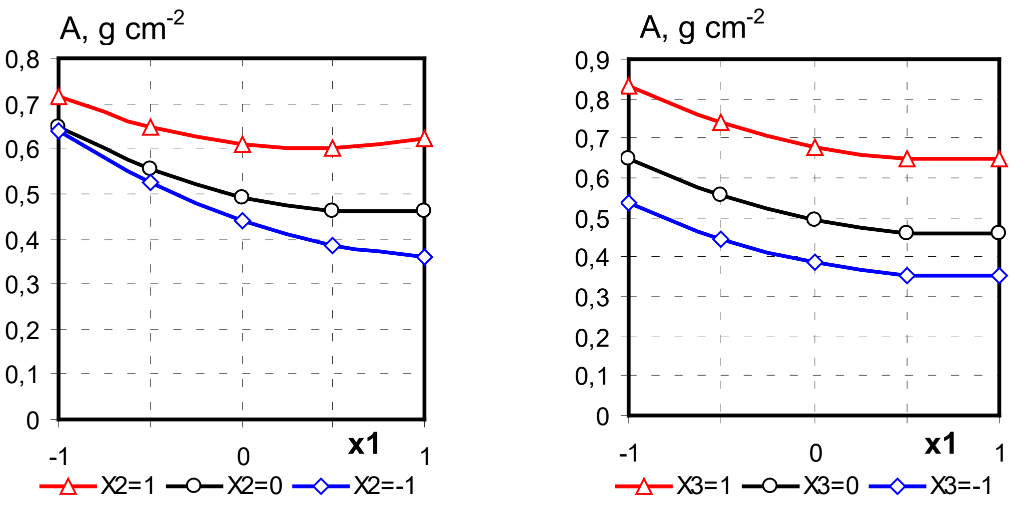

Fig. 8. Dependences of SCC abrasion on the studied factors.

cement concretes when using them for floors is their reduced abrasion. As shown by our experiments (Fig. 8), a significant positive effect of PVAD on abrasion is shown at low values of the polymer-cement ratio (P/C). At P/C = 0.005 and W/B = 0.3, the calculated SCC abrasion is 0.53 g cm^{-2}, and increasing P/C to 0.03 reduces the abrasion to 0.35 g cm^{-2}, i.e. by 34 %. Additional experiments showed that the SCC abrasion without admixtures was 0.83 g cm^{-2}.

Analysis of the resulting set of regression equations shows that the total effect of the components of the studied PM is usually admixture. The choice of PM composition should be determined by both the normalized properties of concrete and technical and economic factors.

CONCLUSIONS

- The possibility of modifying self-compacting fine-grained concrete with polymer admixtures is established, which allows improving their technical properties.
- Polyfunctional modifier (PM), including polycarboxylate superplasticizer and polyvinyl acetate dispersion can reduce the water consumption of self-compacting concrete by 13 - 19 %.
- The use of PFM reduces the water separation of the mixture, helps to maintain a low value of the slump loss over time, and significantly reduces the abrasion of concrete.

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