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MECHANOCHEMICAL ACTIVATION OF MIXED BINDER AND ITS EFFECT ON CONCRETE PROPERTIES

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Abstract. The issues considered in the article are related to the determination of the combined effect of mechanochemical activation of Portland cement and its consumption, ground quartz sand, superplasticizer (hereinafter SP) and amorphous microsilica (hereinafter MS) on the strength and abrasion resistance of concrete. The effect of partial replacement of Portland cement with ground quartz sand was studied, the consumption of which in the mixed binder varied in the range from 0 to 40%. The consumption of MS in the mixed binder varied in the range from 0 to 10%, and the consumption of SP – from 0 to 1% of the Portland cement mass. The consumption of Portland cement in the concrete mix varied in the range from 350 to 450 kg/m^3. The activation period of the binder was 180 sec. The obtained experimental results indicate the possibility of varying the recipe and technological factors to increase the strength of concrete and reduce the consumption of Portland cement in the concrete mix.

The obtained experimental data indicate a significant effect of mechanochemical activation of the mixed binder on the strength of concrete. Of the listed factors, the greatest effect on the compressive strength of concrete is exerted by the consumption of ground sand and SP in the mixed binder. The addition of ground quartz sand (40%) to the mixed binder causes a decrease in the strength of concrete from 35.1 MPa to 22.5 MPa (by 35.9%) at the grade age. An increase in the consumption of SP (up to 1%) in the mixed binder causes an increase in the strength of concrete from 17 MPa to 28 MPa (by 64.7%) at the early stages of hardening and from 35.1 MPa to 49.7 MPa (by 41.6%) at the grade age.

The use of MS (10%) in the composition of the mixed binder provides a relatively insignificant increase in strength (6.5%) at the early stages of curing and (4.6%) at the grade age compared to the control.

The use of mechanical activation provides an increase in concrete strength by 62.4% (at the early stages of hardening) and 25.1% (at the grade age) compared to the control. The combined effect of mechanical activation (180 sec), addition of ground quartz sand (40%), MS addition (10%) and an increase in the consumption of SP (1%) in the composition of the mixed binder (Portland cement consumption 350 kg/m3) causes an increase in the compressive strength of concrete (8,), a decrease in concrete abrasion from 0.33 (40% ground sand) to 0.21 g/cm^2 and a decrease in Portland cement consumption from 350 kg/m^3 (control) to 189 kg/m^3 (by 46%).

Keywords: mechanical activation, Portland cement, ground quartz sand, superplasticizer, microsilica, concrete.

Introduction. Portland cement remains the most expensive component of concrete manufacturing technology, which is explained by the peculiarities of its production. In this regard, ways to reduce the consumption of cement in the composition of concrete, provided that the specified strength is ensured, are becoming increasingly relevant. A promising method for improving the physical and mechanical characteristics of hardened composites is the mechanochemical activation of a mixed binder using active and inert mineral additives. The issues considered in the article are related to determining the combined effect of both the mechanochemical activation of a mixed binder and the consumption of Portland cement, ground quartz sand, SP and MS in it on the strength and abrasion of concrete based on it.

Analysis of the latest research and publications. One of the key tasks in the technology of producing mixed cements is to create optimal combinations of Portland cement with mineral additives. The presence of mineral additives in the composition of the mixed binder increases the potential of concrete based on it. [1-3]. In this regard, the replaceable part of Portland cement with mineral additives [4, 5] contributes to both the economic efficiency of concrete production and the production of concrete with improved properties [6-8].

Various methods have been created to improve the properties of mortar and concrete based on it [9], among which the use of mechanochemical activation of the binder is promising [10, 11]. Among the existing methods for activating the hydration processes of cement compositions, high-speed turbulent mixers are widely used [12]. Activation in a turbulent mixer helps to increase the mobility of the mixture, which allows to reduce the amount of mixing water.

The use of surfactants in the technology of manufacturing resource-saving construction concretes helps to reduce the excess of mixing water, which leads to an increase in the strength of concrete based on them [13–16]. The use of such ultrafine additives as MS contributes to a denser packing of concrete components due to the microscopic size of its particles [17]. The addition of MS to a mixed binder increases adhesion and reduces the porosity of the contact zone of the filler with the binder [18].

It is expected that the use of mechanochemical activation of a mixed binder with the addition of ground quartz sand, MS and SP will lead to a decrease in the consumption of Portland cement while simultaneously increasing the strength and reducing the abrasion of concrete based on it.

Objectives and tasks. The aim of the work is to determine the effect of mechanochemical activation of a mixed binder in the presence of SP on the compressive strength and abrasion resistance of concrete.

Materials and research methods. The mobility of the concrete mixture on the mixed binder was taken as such that it provided a cone settlement of 3-4 cm. Quartz sand was ground to a specific surface of 300 m^2/kg. The activation of the mixed binder compositions was carried out in an aqueous medium, in a turbulent high-speed mixer for 180 sec.

Portland cement PC II/A-K(SH-V)-500R (specific surface area 505 m^2/kg) was used as a binder. Polycarboxylate superplasticizer Relaxol – Super PC was used as a surfactant. Ground quartz sand (specific surface area 300 m^2/kg) and MS (specific surface area 20.000 m^2/kg) were used to replace cement. Concrete mix on non-activated binder (Portland cement consumption 350 kg/m^3) without addition of ground quartz sand, SP and MS was used for control. The composition of concrete mix (control) included Portland cement (350 kg/m^3), quartz sand from Mkr = 2.5 (720 kg/m^3) and crushed granite of fractions 5-20 mm (1235 kg/m^3).

The separate and combined influence of mechanical activation of mixed binder, consumption of Portland cement, ground quartz sand, SP and MS in it on the strength of concrete was estimated by testing concrete cubes with an edge of 10 cm for compression at the age of 3, 7 and 28. The influence of the presented factors on the abrasion of concrete was estimated by testing concrete cubes with an edge of 7.07 cm on the abrasion circle LKI-2 at the age of 28 days of hardening.

A four-factor planned experiment was conducted to determine the effect of variable factors on the strength of samples and abrasion. The plan of the four-factor experiment and the compositions of concrete mixtures (per 1 m^3 of concrete) for making samples is presented in Table 1.

Research results. Table 1 shows the variable factors of the four-factor experiment, namely: a) Portland cement consumption in concrete mix – X_1 (400±50 kg/m^3); b) ground sand consumption in mixed binder – X_2 (20±20%); c) MS consumption – X_3 (5±5%); d) SP concentration – X_4 (0.5±0.5%). The choice of factors is associated with the possibility of ensuring the strength of samples above 35 MPa.

According to the compositions of concrete mixtures given in Table 1, concrete cubes with an edge of 10 cm were tested for compression at the age of 3, 7 and 28 days of hardening. The experimental plan and the strength indicators of concrete for compression (responses) are given in Table 2.

Table 1 – Four-factor experiment plan and concrete mix compositions (per 1 m^3 of concrete)

Comp. numb.	Factor levels				Portland cement, kg/m^3	Ground quartz sand, kg/m^3	Quartz sand, kg/m^3	Granite crushed stone, kg/m^3	MS, kg/m^3	SP, kg/m^3
	X_1	X_2	X_3	X_4						
1	0	0	0	0	304	80	705	1205	16	1.52
2	-	-	-	-	350	0	720	1235	0	0
3	-	+	+	+	189	140	720	1235	21	1.9
4	+	-	+	+	405	0	690	1165	45	4.05
5	+	+	-	+	270	180	690	1165	0	2.7
6	+	+	+	-	243	180	690	1165	27	0
7	0	+	-	-	240	160	705	1205	0	0
8	0	-	+	-	360	0	705	1205	40	0
9	0	-	-	+	400	0	705	1205	0	4
10	+	0	-	-	360	90	690	1165	0	0
11	-	0	+	-	252	70	720	1235	28	0
12	-	0	-	+	280	70	720	1235	0	2.8
13	+	-	0	-	427.5	0	690	1165	22.5	0
14	-	+	0	-	199.5	140	720	1235	10.5	0
15	-	-	0	+	332.5	0	720	1235	17.5	3.32
16	+	-	-	0	450	0	690	1165	0	2.25
17	-	+	-	0	210	140	720	1235	0	1.05
18	-	-	+	0	315	0	720	1235	35	1.58

Table 2 – Experimental design and compressive strength of concrete at the age of 3, 7 and 28 days

Comp. numb.	Responses					
	R^{C}_{COM}, MPa			R^{M}_{COM}, MPa		
	3 days	7 days	28 days	3 days	7 days	28 days
1	23.7	33.2	45.8	33.7	45.3	56.6
2	17	23.2	35.3	27.5	35.2	43.8
3	15.5	22.4	33.8	25.3	33.7	41.6
4	36.9	48.5	65.3	45.6	61.8	77.7
5	20.8	27.1	42	32.2	42.8	52.6
6	12.7	21.3	32.5	24.4	32.1	40.3
7	12.1	19.2	27.1	21.3	27.6	33.5
8	19.4	26.3	40.9	30.5	40.7	50.4
9	33.1	41.2	55.7	37.9	51.5	65.4
10	17.9	24.8	37.3	27.9	37.1	45.7
11	12.4	21.9	32	24.3	32.1	40.6
12	22.1	29.8	42.7	31.2	41.3	50.5
13	20.9	28.9	45.6	34.2	43.2	55
14	8.7	15.3	23.4	17.7	22.8	28.7
15	27.2	34.2	50.2	40.1	48.6	60.1
16	30.4	39.9	58.2	41.4	52.6	67.8
17	14.1	22.6	29.5	19.5	30.2	36.4
18	25.6	33.8	47.5	35.6	45.1	56.4

Note: R^{C}_{COM} – compressive strength of concrete on non-activated binder on the 3rd, 7th and 28th day;

R^{M}_{COM} – compressive strength of concrete on mechanically activated binder on the 3rd, 7th and 28th day.

Experimental statistical models reflecting the influence of variable composition factors on the compressive strength of concrete at 28 days of hardening, on non-activated (1) and mechanically activated (2) binders, are presented on the models:

$$\begin{aligned} R^{cont28}_{com} = {} & 45.8 + 5.3X_1 - 0.0X_1^2 - 0.6X_1X_2 + 0.2X_1X_3 + 1.0\,X_1X_4 \\ & - 8.1X_2 - 1.4X_2^2 + 0.3X_2X_3 - 1.5X_2X_4 \\ & + 1.1X_3 + 0.1X_3^2 + 0.1X_3X_4 \\ & + 6.9X_4 - 3.7X_4^2 \end{aligned} \quad (1)$$

$$\begin{aligned} R^{mech28}_{com} = {} & 56.6 + 6.4X_1 - 0.4X_1^2 - 0.1X_1X_2 + 0.4X_1X_3 + 1.6\,X_1X_4 \\ & - 8.9X_2 - 2.3X_2^2 + 0.3X_2X_3 - 1.0X_2X_4 \\ & + 1.7X_3 - 0.4X_3^2 + 0.4X_3X_4 \\ & + 8.0X_4 - 4.0X_4^2 \end{aligned} \quad (2)$$

Note: R^{mech28}_{com} – strength of concrete based on mechanically activated binder, MPa; R^{cont28}_{com} – strength of concrete on non-activated binder, MPa.

The analysis of mathematical models (1, 2) show that, according to the values of the coefficients for the variable factors, the greatest influence on the compressive strength of concrete for the grade age of hardening is exerted by the consumption of ground sand and SP in the mixed binder.

The effect of the amount of ground sand and the concentration of SP on the strength of the concrete is confirmed by the experimental data, which are graphically reflected in Fig. 1, 2 (factor X_1 is at level -1).

For concrete on non-mechanically activated binder at the age of 3 days, Fig. 1, an increase in SP consumption from 0 to 1% (factors X_1, X_2 and X_3 are at level -1) ensures an increase in concrete strength from 17 MPa to 28 MPa, i.e. by 64.7%. At the age of 7 days, an increase in SP consumption contributes to an increase in concrete strength from 23.1 MPa to 35.1 MPa, i.e. by 52%. At the brand age, there is an increase in concrete strength from 35.1 MPa to 49.7 MPa, i.e. by 41.6%. This allows us to state that the use of SP provides the greatest (of the factors used) increase in concrete strength at the early stages of hardening. For more distant hardening periods, the effect of SP on concrete strength decreases and does not exceed 41.6% at the age of 28 days.

An increase in the consumption of ground quartz sand in the binder causes a decrease in the strength of concrete. For 3-day-old concrete on a non-mechanically activated binder, Fig. 1, an increase in the consumption of ground sand from 0 to 40% (factors X_1, X_3 and X_4 are at level -1) leads to a decrease in the strength of concrete from 17 MPa to 9.4 MPa, i.e. by 44.7%. At the age of 7 days, an increase in the consumption of ground sand leads to a decrease in the strength of concrete from 23.1 MPa to 17.1 MPa, i.e. by 26%. At the grade age, an increase in the consumption of ground sand leads to a decrease in the strength of concrete from 35.1 MPa to 22.5 MPa, i.e. by 35.9%. Thus, it can be stated that the greatest impact on the decrease in the strength of concrete due to the introduction of ground sand into the binder occurs at the early stages of hardening.

An increase in the MS consumption in the binder causes an insignificant increase in the concrete strength. For 3-day-old concrete on a non-mechanically activated binder, Fig. 1, an increase in the MS consumption from 0 to 10% (factors X_1, X_2 and X_4 are at the level of -1) provides an increase in the concrete strength from 17 MPa to 18.1 MPa, i.e. by 6.5%. At the age of 7 days, an increase in the concrete strength is observed from 23.1 MPa to 24.3 MPa, i.e. by 5.2%. At the grade age, the increase in concrete strength due to the introduction of MS does not exceed 4.6% (from 35.1 MPa to 36.7 MPa).

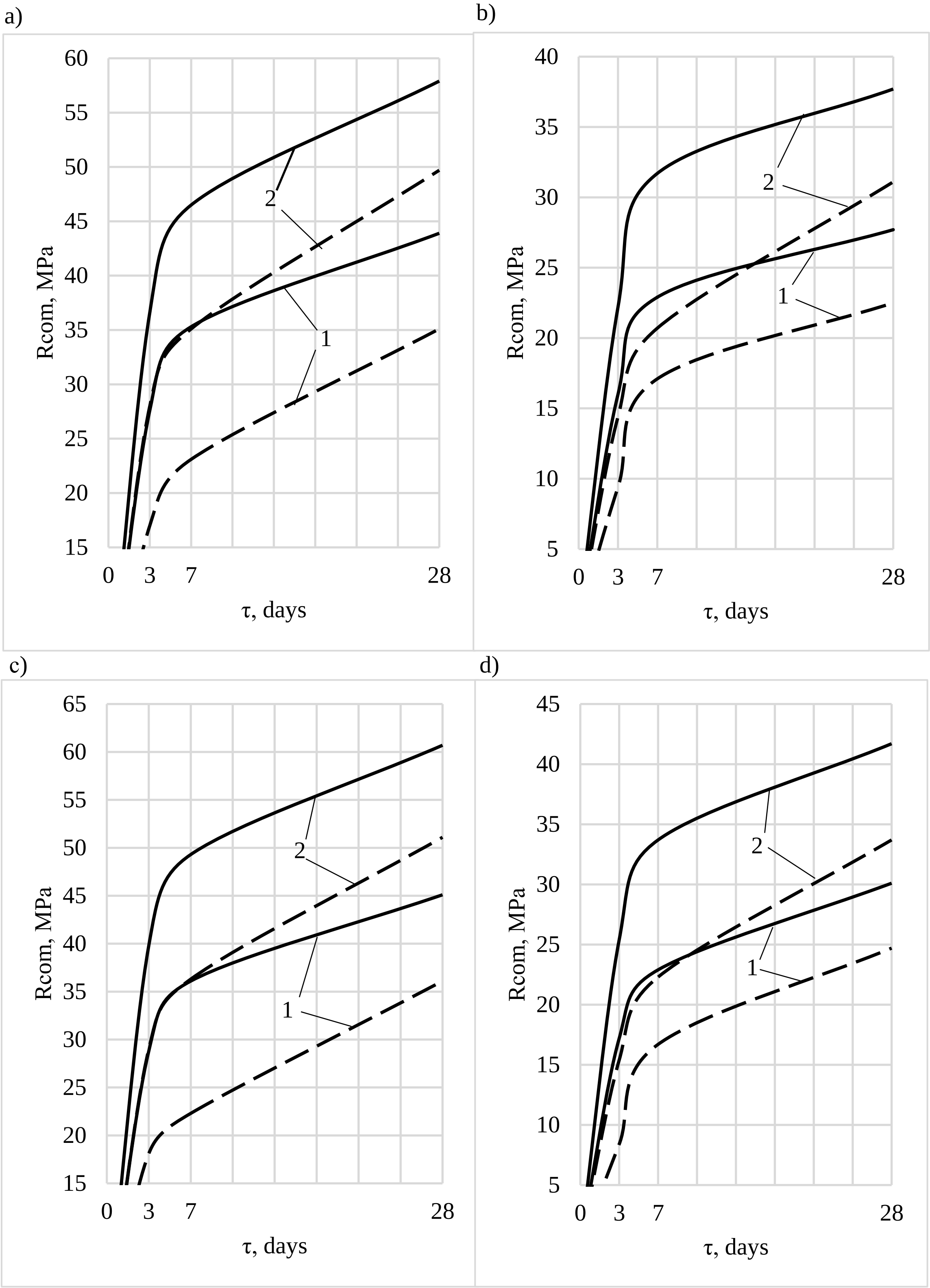

Fig. 1. The influence of curing time on the strength of concrete:
a, b – content of ground sand in the binder 0 and 40%, respectively, content of microsilica 0%;
c, d – content of ground sand in the binder 0 and 40%, respectively, content of microsilica 10%;
--------- – solution on mechanically activated (for 180 sec) binder;
- - - - - - – solution on non-activated binder (control);
1, 2 – superplasticizer consumption 0 and 1% respectively (from the mass of the cement)

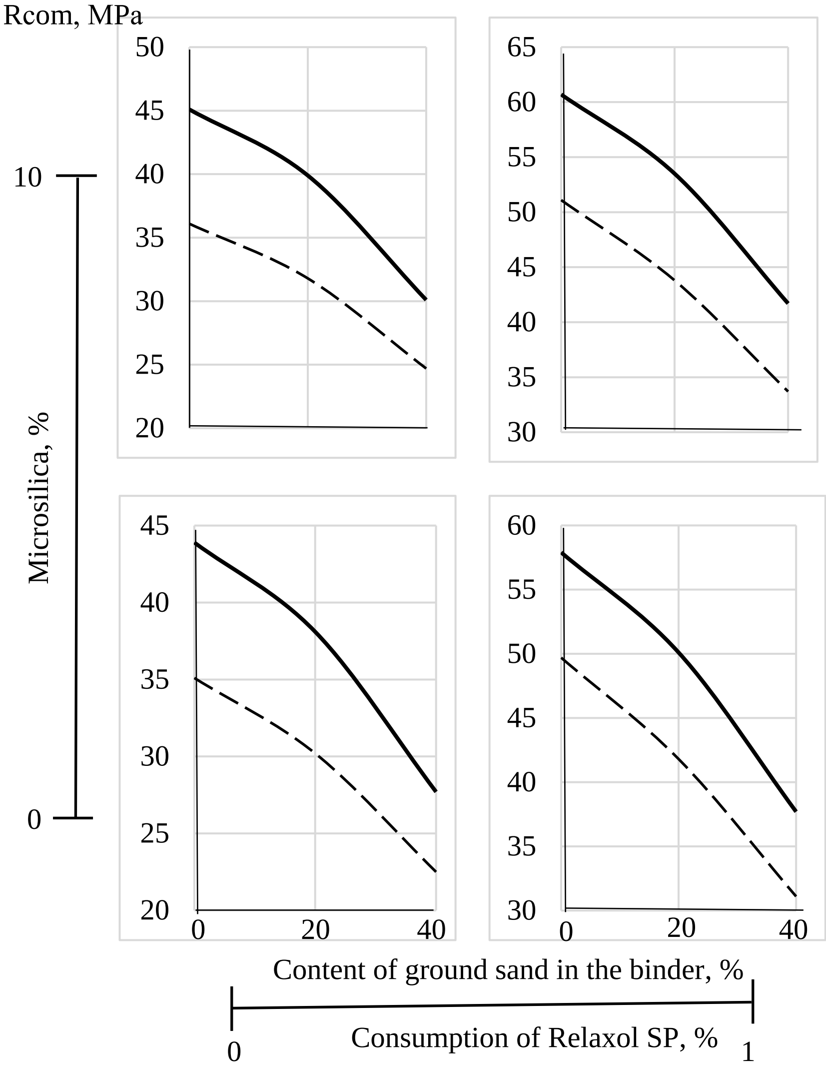

Fig. 2. The influence of the consumption of ground quartz sand and the concentration of SP in the binder on the compressive strength of concrete at 28 days of age:
--------- – solution on mechanically activated binder;
- - - - - - – solution on non-activated binder (control)

Mechanical activation of the binder leads to an increase in the strength of concrete. It should be noted that the use of mechanical activation of the binder allows to increase the intensity of hydration processes and significantly increase the strength of the final product. This allows to do without additional methods of increasing the strength of concrete during the strength gain process [19]. The effect of mechanical activation for old concrete, Fig. 2, is on average 22% increase in strength (compared to the strength of concrete on a non-activated binder). For 3-day-old concrete, Fig. 1, the use of mechanical activation for 180 sec (factors X_1, X_2, X_3 and X_4 are at level -1) provides an increase in strength from 17 MPa to 27.6 MPa, i.e. by 62.4%. At 7-day age, mechanical activation provides an increase in concrete strength from 23.1 MPa to 35.3 MPa, i.e. by 52.8%. At grade age, an increase in concrete strength is observed from 35.1 MPa to 43.9 MPa, i.e. by 25.1%.

The experimental data shown in Fig. 1, 2 indicate that the combined action of mechanical activation of the mixed binder, the introduction of SP and MK into its composition causes an increase in the strength of concrete from 35.1 MPa (control) to 41.7 MPa (activation, factors X_2, X_3 and X_4 are at level 1), i.e. by 18.8%, and reduces the consumption of Portland cement from 350 kg/m^3 to 189 kg/m^3 (by 46%).

As for the influence of variable factors on the abrasion of concrete, in accordance with the compositions of concrete mixtures given in Table 1, a test was carried out on concrete cubes with an edge of 7.07 cm on an abrasion circle at the age of 28 days of hardening. The experimental design and average values of concrete abrasion are shown in Table 3.

Table 3 – Experimental design and concrete abrasion

Com. num.	Factor levels				Control			Mechanical activation of mixed binder		
	X1	X2	X3	X4	mass of samples, g: before abrasion	mass of samples, g: after abrasion	Abrasion, g/cm^2	mass of samples, g: before abrasion	mass of samples, g: after abrasion	Abrasion, g/cm^2
1	0	0	0	0	826	819	0.15	838	832	0.12
2	-	-	-	-	808	797	0.22	817	807	0.2
3	-	+	+	+	822	810	0.24	836	825	0.21
4	+	-	+	+	816	811	0.11	824	820	0.09
5	+	+	-	+	820	809	0.21	829	820	0.17
6	+	+	+	-	821	808	0.25	827	826	0.21
7	0	+	-	-	817	802	0.3	822	810	0.25
8	0	-	+	-	807	799	0.17	816	819	0.15
9	0	-	-	+	814	807	0.14	818	813	0.11
10	+	0	-	-	805	796	0.19	813	805	0.16
11	-	0	+	-	833	822	0.23	845	834	0.22
12	-	0	-	+	808	798	0.19	821	812	0.17
13	+	-	0	-	808	800	0.17	816	809	0.14
14	-	+	0	-	828	811	0.33	840	827	0.27
15	-	-	0	+	812	804	0.16	822	815	0.14
16	+	-	-	0	801	793	0.15	809	803	0.12
17	-	+	-	0	824	810	0.29	831	818	0.26
18	-	-	+	0	815	806	0.18	818	811	0.15

Experimental statistical models reflecting the influence of variable composition factors on the abrasion resistance of concrete on the 28th day of hardening, on non-activated (1) and mechanically activated (2) binders, are presented on the models:

$$G^{cont28} = 15.1 - 2.8X_1 + 1.5X_1^2 - 0.5X_1X_2 - 0.3X_1X_3 + 0.1X_1X_4 + 4.5X_2 + 3.7X_2^2 - 0.3X_2X_3 - 0.7X_2X_4 - 1.2X_3 + 0.3X_3^2 - 0.2X_3X_4 - 3.1X_4 + 1.0X_4^2 \quad (3)$$

$$G^{act28} = 12.3 - 2.9X_1 + 1.8X_1^2 - 0.5X_1X_2 + 0.0X_1X_3 + 0.1X_1X_4 + 3.7X_2 + 2.5X_2^2 - 0.3X_2X_3 - 0.3X_2X_4 - 0.9X_3 + 1.1X_3^2 - 0.3X_3X_4 - 2.9X_4 + 1.2X_4^2 \quad (4)$$

Note: G^{act28} – abrasion resistance of concrete on mechanically activated binder, g/cm^2; G^{cont28} – abrasion resistance of concrete on non-activated binder, g/cm^2.

Analysis of mathematical models (3, 4) show that, according to the values of the coefficients for the variable factors, the greatest influence on the abrasion of concrete at the grade age of hardening is exerted by the consumption of ground sand (X_2). The influence of individual variable factors (X_1, X_2, X_3 and X_4) on the abrasion of concrete at the grade age of hardening in the minimum and maximum zones both on the mechanically activated mixed binder and on the non-activated mixed binder is presented in single-factor graphical dependencies, Fig. 3.

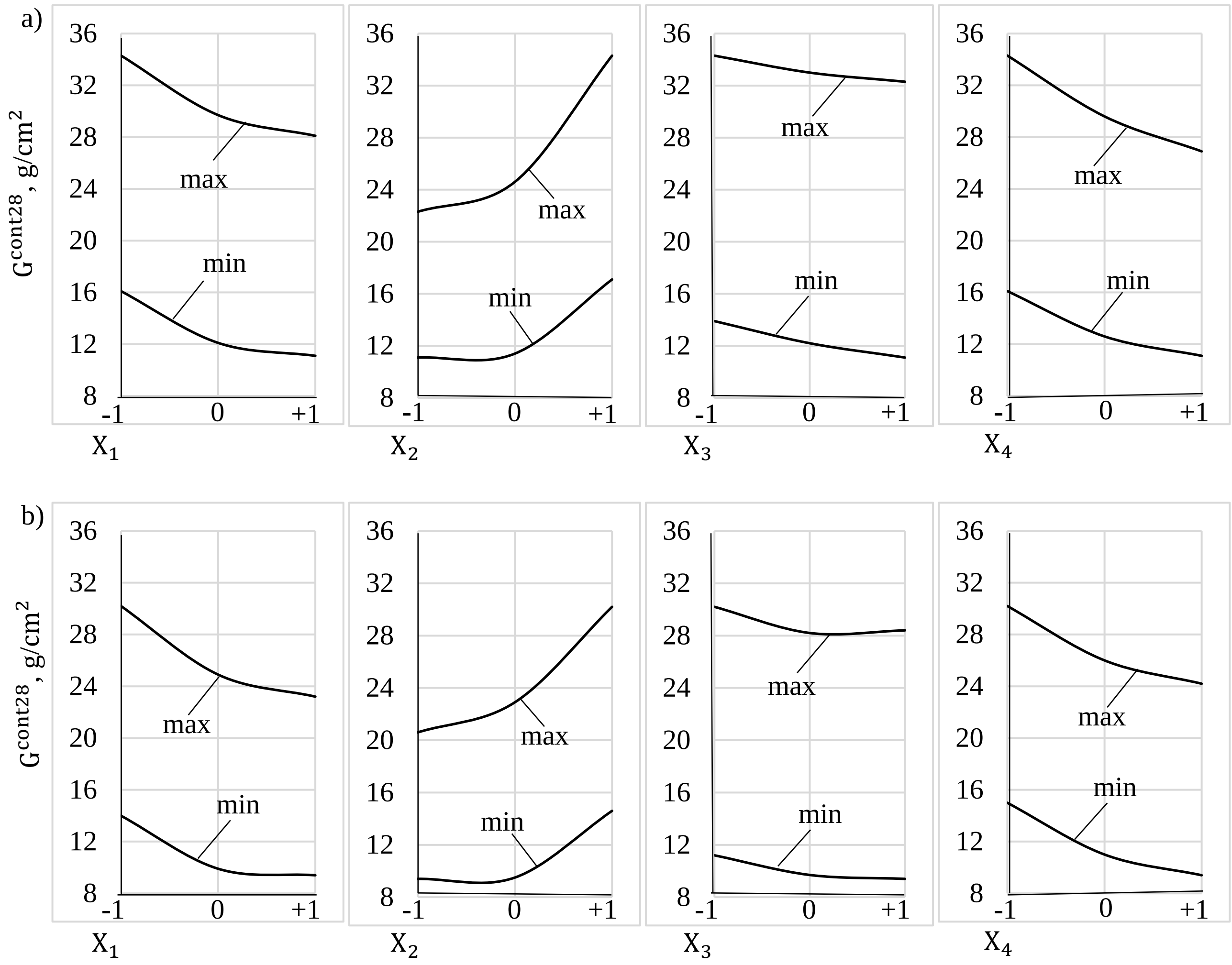

Fig. 3. The influence of variable factors (X_1, X_2, X_3 and X_4) on the abrasion of concrete:
a – solution on non-activated binder (control);
b – solution on mechanically activated (for 180 sec) binder

An increase in the consumption of ground sand from 0 to 40% (of the cement mass) in the mixed binder causes an increase in abrasion in the maximum zones from 0.22 to 0.34 g/cm^2 (control) and from 0.2 to 0.3 g/cm^2 (mechanical activation for 180 sec). In the minimum zones, an increase in the consumption of ground sand in the mixed binder causes an increase in abrasion from 0.11 to 0.17 g/cm^2 (control) and from 0.09 to 0.15 g/cm^2 (mechanical activation for 180 sec).

The second factor influencing concrete abrasion is the consumption of Portland cement (X_1) in the mixed binder. An increase in Portland cement consumption from 350 to 450 kg/m^3 in concrete causes a decrease in abrasion in the maximum zones from 0.34 to 0.28 g/cm^2 (control) and from 0.3 to 0.23 g/cm^2 (mechanical activation 180 sec). In the minimum zones, an increase in Portland cement consumption in concrete causes a decrease in abrasion from 0.16 to 0.11 g/cm^2 (control) and from 0.14 to 0.09 g/cm^2 (mechanical activation 180 sec).

The next factor in terms of impact on concrete abrasion is the concentration of SP (X_4) in the mixed binder. Addition of SP to the composition of concrete mix has a useful compacting effect and allows to reduce the number of pores in the finished concrete. The use of SP makes it possible to reduce the use of fibers and modifiers to increase resistance to abrasion (the effect is achieved both from the combined use of some of them) [20, 21]. An increase in the concentration of SP in the mixed binder causes a decrease in abrasion in the maximum zones from 0.34 to 0.27 g/cm^2 (control) and from 0.3 to 0.24 g/cm^2 (mechanical activation for 180 sec). In the minimum growth zones, the concentration of SP causes a decrease in abrasion from 0.16 to 0.11 g/cm^2 (control) and from 0.15 to 0.09 g/cm^2 (mechanical activation for 180 sec).

The last factor influencing the concrete abrasion is the consumption of MS (X_3) in the mixed binder. An increase in the consumption of MS in the mixed binder causes a decrease in abrasion in the maximum zones from 0.34 to 0.32 g/cm^2 (control) and from 0.3 to 0.28 g/cm^2 (mechanical activation for 180 sec). An increase in the concentration of SP in the minimum zones causes a decrease in abrasion from 0.13 to 0.11 g/cm^2 (control) and from 0.11 to 0.09 g/cm^2 (mechanical activation for 180 sec).

Thus, the use of mechanical activation and mineral additives allows one to obtain a more uniform and compacted structure of the binder, which helps to improve the resistance to abrasion of concrete.

Conclusions:

1. The combined effect of mechanical activation (180 sec), addition of ground quartz sand (40%), MS additive (10%) and increase in SP consumption (1%) in the composition of the mixed binder (Portland cement consumption 350 kg/m^3) causes an increase in the compressive strength of concrete from 35.1 MPa (control) to 41.7 MPa (by 18.8%) and reduces Portland cement consumption from 350 kg/m^3 (control) to 189 kg/m^3 (by 46%). The reduction in Portland cement consumption occurs (mainly) due to the introduction of ground sand into its composition (up to 40%), the negative impact of which on the strength of concrete is compensated by the use of mechanical activation and SP.

2. The combined effect of the above factors in the composition of the mixed binder (portland cement consumption 350 kg/m^3) causes a decrease in concrete abrasion from 0.33 (40% ground sand) to 0.21 g/cm^2. The greatest influence on concrete abrasion at the grade age of hardening is exerted by the consumption of ground sand in the composition of the mixed binder, which is compensated by the combined effect of other factors (mechanical activation, MC and SP).

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МЕХАНОХІМІЧНА АКТИВАЦІЯ ЗМІШАНОГО В'ЯЖУЧОГО ТА ЇЇ ВПЛИВ НА ВЛАСТИВОСТІ БЕТОНУ

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Анотація. Розглянуті у статті питання пов'язані з визначенням сумісного впливу механохімічної активації портландцементу та його витрати, меленого кварцового піску, суперпластифікатору (в подальшому СП) та аморфного мікрокремнезему (в подальшому МК) на міцність та стираність бетону. Досліджувався вплив часткової заміни портландцементу меленим кварцовим піском, витрата якого у змішаному в'яжучому варіювалася в діапазоні від 0 до 40%. Витрата МК у змішаному в'яжучому варіювалася в діапазоні від 0 до 10%, а витрата СП – від 0 до 1% маси портландцементу. Витрата портландцементу у складі бетонної суміші варіювалася в діапазоні від 350 до 450 кг/м^3. Термін активації в'яжучого складав 180 сек. Одержані експериментальні результати свідчать про можливість варіювання рецептурно-технологічних факторів для підвищення міцності бетону та зниження витрати портландцементу в складі бетонної суміші.

Одержані експериментальні дані свідчать про значний вплив механохімічної активації змішаного в'яжучого на міцність бетону. Із перерахованих факторів найбільший вплив на міцність бетону на стиск надає витрата меленого піску та СП у складі змішаного в'яжучого. Добавка меленого кварцового піску (40%) до складу змішаного в'яжучого викликає зниження міцності бетону з 35,1 МПа до 22,5 МПа (на 35,9%.) в марочному віці. Зростання витрати СП (до 1%) у складі змішаного в'яжучого викликає підвищення міцності бетону з 17 МПа до 28 МПа (на 64,7%) на ранніх термінах тверднення та з 35,1 МПа до 49,7 МПа (на 41,6%.) в марочному віці. Використання МК (10%) у складі змішаного в'яжучого забезпечує відносно незначне зростання міцності (6,5%) на ранніх термінах тверднення та (4,6%) у марочному віці в порівнянні з контролем.

Використання механоактивації забезпечує зростання міцності бетону на 62,4% (на ранніх термінах тверднення) та 25,1% (у марочному віці) в порівнянні з контролем. Сумісна дія механоактивації (180 сек), добавки меленого кварцового піску (40%), добавки МК (10%) та збільшення витрати СП (1%) у складі змішаного в'яжучого (витрата портландцементу 350 кг/м^3) викликає зростання міцності бетону на стиск з 35,1 МПа (контроль) до 41,7 МПа (на 18,8%), зниження стираності бетону від 0,33 (40% меленого піску) до 0,21 г/см^2 та зниження витрати портландцементу з 350 кг/м^3 (контроль) до 189 кг/м^3 (на 46%).

Ключові слова: механоактивація, портландцемент, мелений кварцовий пісок, суперпластифікатор, мікрокремнезем, бетон.

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