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MECHANOACTIVATION OF MIXED BINDING AGENT AND ITS INFLUENCE ON THE STRENGTH OF CONSTRUCTION MORTAR

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Abstract. The issues considered in the article are related to determining the effect of mechanical activation of a mixed binder on the properties of a building mortar. The study involved partial replacement of cement with ground crystalline quartz sand and amorphous microsilica (hereinafter MS) in combination with the use of the superplasticizer Relaxol-Super PC (hereinafter SP). The amount of ground sand was adjusted in the range from 0 to 40%, MS from 0 to 10% and SP from 0 to 1% of the binder mass. The activation period of the binder was 180 sec. The use of this formulation allows increasing the strength and reducing the consumption of Portland cement in the technology of manufacturing a building mortar. The obtained experimental data confirmed the influence of formulation and technological factors on the water-solid ratio of the cement-containing composition. It was found that the main contribution to the reduction of the water-solid ratio (provided that equiviscous compositions are obtained) is made by mechanical activation in combination with the replacement of 40% of cement with ground quartz sand and the addition of 1% SP. The water-solid ratio decreases by more than 50%, which has a positive effect on the strength of the solution.

The increase in the strength of the mortar with the addition of SP reached 93% (at the early stages of hardening) and 56% (at the grade age) compared to the control. The use of MS in the composition of the mortar provides a relatively small increase in strength (12%) at the early stages of hardening and 8% at the grade age compared to the control.

The use of mechanical activation alone provides an increase in the strength of the mortar by 18% (at the early stages of hardening) and 13% (at the grade age) compared to the control. The combined effect of mechanical activation, SP and MS in the composition of the building solution compensates for the negative impact of ground quartz sand and has a positive effect on the growth of strength (up to 38%), ensuring a reduction in cement consumption by 40%.

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

Introduction. In the technology of manufacturing mortar, the most expensive component is cement. In this regard, mixed cements with the use of active and inert mineral additives are becoming increasingly relevant. A promising method for improving the physical and mechanical characteristics of hardened composites is the use of mechanical activation. The issues considered in the article are related to determining the combined effect of the technological factor (mechanical activation), as well as the formulation factors (ground quartz sand, SP and MS) on the strength of the mortar.

Analysis of the latest research and publications. One of the important problems of the technology of production of mixed cements is the creation of optimal combinations of Portland cement with mineral additives, the presence of which increases the potential capabilities of the binder [1-3]. In this regard, the replaceable part of Portland cement with mineral additives [4, 5], in addition to economic efficiency, helps to obtain a binder with improved properties [6-8].

To solve the problem of improving the properties of cement stone and building composites based on it, various methods have been created [9], among which mechanochemical methods of activating the binder are promising [10, 11]. Among the existing methods of activating the hydration processes of cement compositions, turbulent high-speed mixers of various designs are widely used [12].

The use of surfactants is extremely important in the technology of manufacturing resource-saving building solutions [13-15]. Such additives are often used both individually and in combination with other additives of synthetic or natural origin [16]. Their presence reduces excess water during the preparation of the mortar, which increases its strength [17, 18].

The use of such ultrafine additives as MS promotes a denser packing of concrete components due to the microscopic size of its particles [19]. To maintain the proper consistency of concrete containing MS, it is also necessary to use SP [20]. The addition of MS increases adhesion and reduces the porosity of the contact zone of the filler with the cement mortar [21].

It is expected that the use of mechanical activation in combination with the use of ground quartz sand, MS and SP will lead to a decrease in the consumption of Portland cement while simultaneously increasing the strength of the mortar.

Objectives and tasks. The aim of the work is to determine the effect of mechanical activation of a mixed binder in the presence of SP on the compressive strength of a building mortar.

Materials and research methods. The consistency of the cement-water composition with the addition of ground quartz sand was taken to be such that its spread diameter on a shaking table was in the range of 140±5 mm. Quartz sand was ground in a ball mill for 60 minutes. Activation of only Portland cement and a mixture of Portland cement with ground sand was carried out in an aqueous medium, in a mechanical activator for 180 sec.

Polycarboxylate superplasticizing additive Relaxol – Super PC was used as an additive for plasticizing the mixture. Ground quartz sand (specific surface area 0.056 m^2/g) and MS (specific surface area 20 m^2/g) were used to replace cement.

Cement-sand mortar on a non-mechanically activated binder without the addition of ground quartz sand, SP and MS was used for control. The separate and combined effects of mechanical activation, ground quartz sand, SP and MS on the strength of the mortar were assessed by testing 4x4x16 cm beam samples for compression at the age of 1, 7 and 28 days of hardening. The composition of the mortar mixture for making the samples was taken as 1:1 (binder:sand). The compositions of the mixtures for making the samples were taken as given in Table 1. A three-factor experiment was conducted to determine the effect of variable factors on the strength of the samples.

Table 1 – Three-factor experiment plan, mixture compositions and the effect of RTF on W/S

Composition number	Factor levels			Portland cement, %	Ground quartz sand, %	SP, %	MS, %	W/S	
	X_1	X_2	X_3					control	activation
1	-	-	-	100	0	0	0	0.377	0.344
2	-	+	-	100	0	1	0	0.225	0.215
3	0	0	-	80	20	0.5	0	0.26	0.245
4	+	-	-	60	40	0	0	0.333	0.309
5	+	+	-	60	40	1	0	0.204	0.187
6	-	0	0	100	0	0.5	5	0.251	0.238
7	0	-	0	80	20	0	5	0.345	0.324
8	0	0	0	80	20	0.5	5	0.241	0.228
9	0	+	0	80	20	1	5	0.223	0.201
10	+	0	0	60	40	0.5	5	0.226	0.213
11	-	-	+	100	0	0	10	0.36	0.341
12	-	+	+	100	0	1	10	0.22	0.211
13	0	0	+	80	20	0.5	10	0.236	0.224
14	+	-	+	60	40	0	10	0.33	0.305
15	+	+	+	60	40	1	10	0.202	0.186

Table 1 shows the plan of the three-factor experiment and the experimental data reflecting the influence of the recipe and technological factors (RTF), namely: a) the content of ground sand in the binder – X_1 (20±20%); b) the concentration of SP – X_2 (0.5±0.5%); c) the consumption of MS – X_3 (5±5%); d) mechanical activation (180 sec) on the water-solid ratio (W/S) of cement-containing aqueous compositions. The choice of factors is associated with the possibility of ensuring the strength of samples above 30 MPa.

Research results. In the studies, Portland cement PC II/A-Sh-500 was used as a binder. The binder meets the requirements of DSTU B V.2.7-46:2010 "General-purpose cements. Specifications". The mixed binder was obtained by jointly grinding Portland cement and quartz sand in an amount of 20 and 40%. Quartz sand with Msz = 2.2 was used as a filler for the mortar.

The experimental data presented in Table 1 indicate that the use of mechanical activation, ground quartz sand, SP and MS in the cement-water composition has a positive effect on reducing the water-solid ratio of equiviscosity compositions from 0.377 (control) to 0.186 (activation, maximum consumption), i.e. by more than 46%. It should be noted that the main contribution to the decrease in the water-solid ratio is provided by SP (the W/S ratio decreases from 0.377 to 0.223, i.e. by almost 41%). The second largest influence on the decrease in the W/S ratio is the factor of ground sand (it decreases from 0.377 to 0.333, i.e. by more than 11%). The third factor in terms of influence on the reduction of the W/S ratio is the mechanical activation factor (it decreases from 0.377 to 0.344, i.e. by more than 8%), the last factor in terms of influence is MS (it decreases from 0.377 to 0.36, i.e. by more than 4%).

The compressive strength properties of the mortar (responses) are given in Table 2.

Table 2 – Compressive strength of mortar

Composition number	Responses					
	R_{COM}^{CONT}, MPa			R_{COM}^{MECH}, MPa		
	1 day	7 days	28 days	1 day	7 days	28 days
1	21.5	39.8	46.0	25.4	44.7	51.8
2	41.5	68.7	71.9	51.9	76.8	83.7
3	18.3	37.3	43.0	24.0	42.9	50.3
4	12.1	24.1	31.2	15.6	27.7	36.1
5	26.5	47.0	50.9	31.1	52.3	56.4
6	36.9	57.1	62.4	43.9	63.2	70.5
7	12.7	29.5	38.0	15.4	33.6	42.3
8	21.3	46.2	52.8	24.8	54.9	60.1
9	20.3	57.4	60.6	25.9	67.6	67.9
10	20.2	36.9	40.9	26.9	42.2	49.1
11	24.1	43.5	49.7	29.4	47.5	52.5
12	43.4	72.2	75.9	54.2	79.3	87.2
13	21.9	48.3	52.5	30.5	57.9	61.3
14	12.3	25.5	32.1	15.6	29.6	38.7
15	24.6	49.1	56.1	32.7	54.7	63.8

Note: R_{COM}^{CONT} – compressive strength of mortar on non-activated binder on the 1st, 7th and 28th day;

R_{COM}^{MECH} – compressive strength of mortar on mechanically activated binder on the 1st, 7th and 28th day.

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

$$R_{com}^{cont28} = 49{,}8 - 9{,}2X_1 + 2{,}6X_1^2 - 1{,}4X_1X_2 + 0{,}2X_1X_3 + 11{,}9X_2 + 0{,}3X_2^2 + 0{,}7X_2X_3 + 2{,}2X_3 - 1{,}3X_3^2 \quad (1)$$

$$R_{com}^{mech28} = 57{,}2 - 10{,}1X_1 + 3{,}3X_1^2 - 2{,}6X_1X_2 + 0{,}6X_1X_3 + 13{,}7X_2 - 1{,}4X_2^2 + 1{,}0X_2X_3 + 2{,}7X_3 - 0{,}7X_3^2 \quad (2)$$

Note: R_{com}^{mech28} – strength of mortar based on mechanically activated binder; R_{com}^{cont28} – strength of mortar on non-activated binder.

Analysis of mathematical models (1, 2) indicate that, according to the values of the coefficients for the variable factors, the greatest influence on the compressive strength of the mortar for the grade age of hardening is exerted by the content of ground sand and SP in it.

The effect of the amount of ground sand and the concentration of SP on the strength of the mortar is confirmed by the experimental data, which are graphically reflected in Fig. 1, 2.

For the mortar on a non-mechanically activated binder at the age of one day, Fig. 1, an increase in the consumption of SP from 0 to 1% (factors X_1 and X_3 are at the level of -1) ensures an increase in the strength of the mortar from 21.5 MPa to 41.5 MPa, i.e. almost 2 times. At the age of 7 days, an increase in the consumption of SP contributes to an increase in the strength of the mortar from 39.8 MPa to 68.7 MPa, i.e. more than 72%. At the brand age, the mortar strength increases from 46 MPa to 71.9 MPa, i.e. by more than 56%. This allows us to state that the use of SP provides the greatest (of the factors used) strength increase at the early stages of hardening. For more distant hardening periods, the effect of SP on the mortar strength decreases and does not exceed 56% at the age of 28 days.

An increase in the consumption of ground quartz sand in the binder leads to a decrease in the strength of the building mortar. For the building mortar at the age of one day on a non-mechanically activated binder, Fig. 1, an increase in the consumption of ground sand from 0 to 40% (factors X_2 and X_3 are at the level of -1) leads to a decrease in the strength of the mortar from 21.5 MPa to 12.1 MPa, i.e. by almost 44%. At the age of 7 days, an increase in the consumption of ground sand leads to a decrease in the strength of the mortar from 39.8 MPa to 24.1 MPa, i.e. by more than 39%. At the brand age, the increase in the consumption of ground sand leads to a decrease in the mortar strength from 46 MPa to 31.2 MPa, i.e. by more than 32%. Thus, it can be stated that the greatest impact on the decrease in the mortar strength due to the introduction of a binder into the composition occurs at the early stages of hardening.

The increase in the consumption of MS in the binder leads to an insignificant increase in the mortar strength. For a daily-aged mortar on a non-mechanically activated binder, Fig. 1, an increase in the consumption of MS from 0 to 10% (factors X_1 and X_2 are at the level of -1) ensures an increase in the mortar strength from 21.5 MPa to 24.1 MPa, i.e. by almost 12%. At the age of 7 days, an increase in the mortar strength is observed from 39.8 MPa to 43.5 MPa, i.e. by more than 9%. At the brand age, the increase in the strength of the solution due to the introduction of MS does not exceed 8% (from 46 MPa to 49.7 MPa).

Mechanical activation of the binder leads to an increase in the strength of the mortar. The effect of mechanical activation for the mortar at the brand age, Fig. 2, is on average 15% (compared to the strength of the mortar on a non-activated binder) of the increase in strength. For the mortar at the age of one day on a mechanically activated binder, Fig. 1, the use of mechanical activation for 180 sec (factors X_1, X_2 and X_3 are at the level of -1) provides an increase in the strength of the mortar from 21.5 MPa to 25.4 MPa, i.e. by more than 18%. At the age of 7 days, mechanical activation provides an increase in the strength of the mortar from 39.8 MPa to 44.7 MPa, i.e. by more than 12%. At the brand age, an increase in the strength of the mortar is observed from 46 MPa to 51.8 MPa, i.e. by more than 13%.

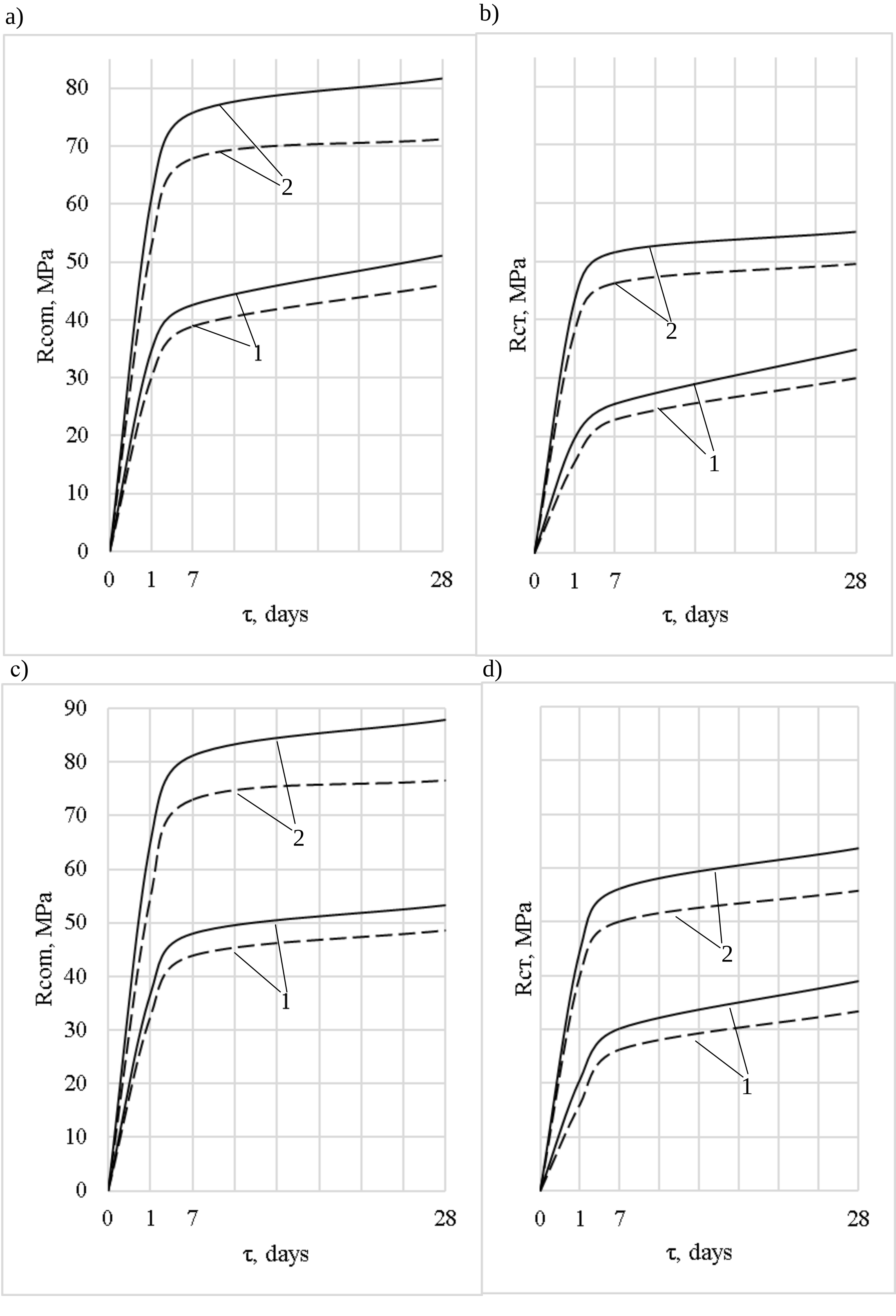

Fig. 1. The effect of curing time on the strength of mortar:
a, b – content of ground sand in the binder 0 and 40%, respectively, content of microsilica 0%;
c, d – content of ground sand in the binder 0 and 40%, respectively, content of microsilica 10%;
--------- – solution on mechanically activated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

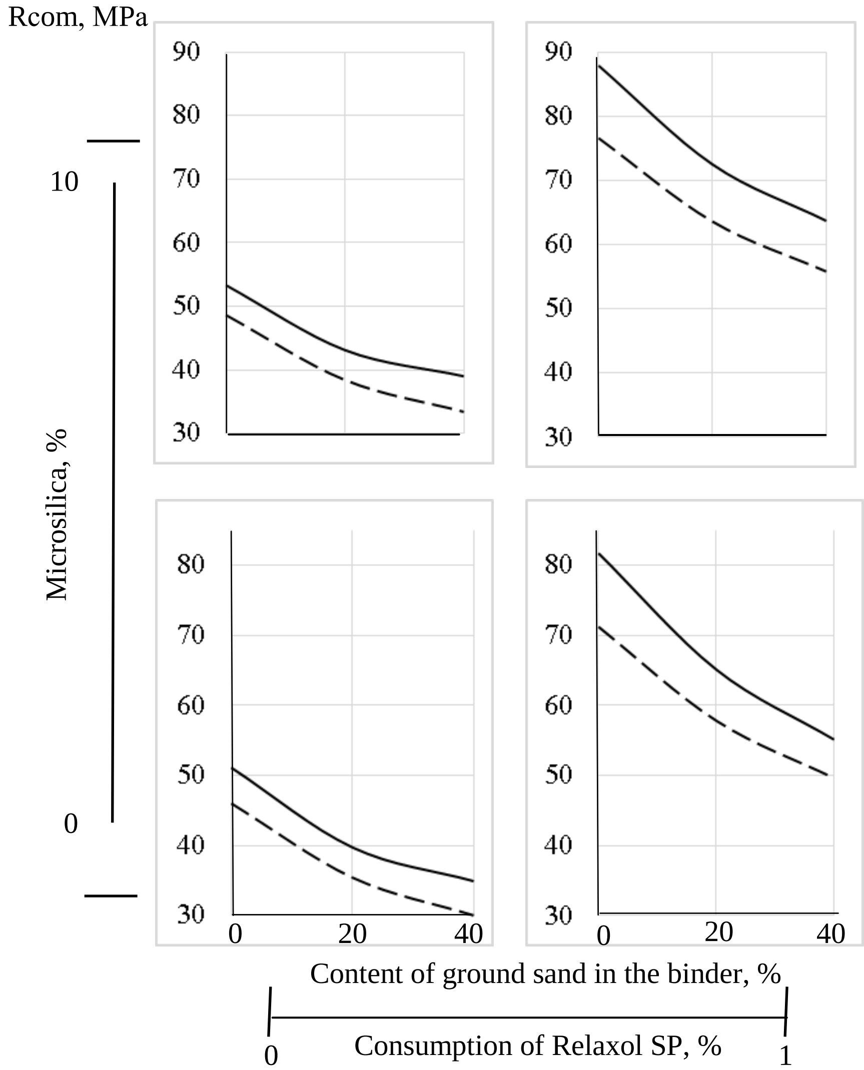

Fig. 2. The effect of the content of ground quartz sand and the concentration of SP in the binder on the compressive strength of the mortar at 28 days of age:
--------- – solution on mechanically activated binder;
- - - - - - – solution on non-activated binder (control)

Shown in Fig. 1, 2 experimental data indicate that the combined effect of mechanical activation, introduction of SP and MS into the composition of the building solution compensates for the negative effect of ground quartz sand and has a positive effect on the growth of compressive strength. Such a composition provides an increase in strength from 46 MPa (control) to 63.8 MPa (activation, factors X_1, X_2 and X_3 are at level 1), i.e. by more than 38% and reduces the consumption of Portland cement from 30 to 40%.

Conclusions:

1. An increase in the level of variable factors (ground quartz sand, SP and MS in the composition of the mortar) and the use of mechanical activation have a positive effect on the decrease in the water-solid ratio of equal-viscosity mortar mixtures (on average up to 50% compared to the control). The main contribution to the decrease in the water-solid ratio is provided by SP (almost 41% of the total).

2. The combined effect of mechanical activation, SP (1%) and MS (10%) in the composition of the mortar compensates for the negative impact of ground quartz sand (40%) and has a positive effect on the growth of its strength at grade age, which is 35–40% (compared to the control).

References

[1] M.A. Sanitsky, T.P. Kropivnitskaya, V.M. Gevyuk, *Klinkerno-efektyvni tsementy ta betony shvydkoho tverdinnia*. Monohrafiia. Lviv: TOV «Prostir-M, 2021.

[2] L.I. Dvorkin and others, *Efektivni tehnologiyi betoniv i rozchiniv iz zmicnennyam tehnogennoyi sirovini*. Monografiya. Rivne: NUVGP, 2017.

[3] R.F. Runova, Yu.L. Kosovsky, *Tehnologiya modifikovanih budivelnih rozchiniv*. Kiyiv: KNUBA, 2007.

[4] S.V. Koval, *Modeling and optimization of the composition and properties of modified concrete*. Odessa: Astroprint, 2012.

[5] V. I. Gots, *Betoni ta budivelni rozchini*. Kiyiv: UVPK Eks Ob, 2003.

[6] N.V. Kondratieva, "Nanotekhnolohii u vyrobnytstvi budivelnykh materialiv", *Budivnytstvo Ukrainy*, no. 6, pp. 2-9, 2012.

[7] B.G. Rusin, *Visokofunkcionalni betoni na osnovi portlandcementiv, modifikovanih ultradispersnimi mineralnimi dobavkami*: avtorec. dis. na zdobuttya nauk. st. k.t.n. za spec. 05.23.05. Nacionalnij universitet "Lvivska politehnika". Lviv, 2014.

[8] A.V. Usherov-Marshak, A.V. Kabus, "Funkcionalno-kinetichnij analiz vplivu dobavok na tverdinnya cementu", *Neorganichni materiali*, vol. 52, no. 4, pp. 479-484, 2016. doi.org/10.1134/S0020168516040129

[9] V.N. Vyrovoy, *Kompozicijni budivelni materiali ta konstrukciyi. Struktura, samoorganizaciya, vlastivosti*. Odesa: Vid-vo "TES", 2010.

[10] L.I. Dvorkin, O.L. Dvorkin, Yu.V. Garnitsky, *Modifikovani zolovmisni suhi budivelni sumishi dlya muruvalnih ta klejovih rozchiniv*. NUVGP. Rivne, 2013.

[11] M.V. Shpyrko, T.M. Dubov, "Doslidzhennya vplivu elektromagnitnoyi aktivaciyi koncentrovanoyi cementnoyi suspenziyi na vlastivosti cementnogo kamenyu ta betonu", *Visnik PDABA*, no. 2, pp. 102-107, 2020.

[12] A.G. Maslov, Yu.S. Salenko, E.V. Stukota, "Rozrobka ustanovki dlya vibromehanichnoyi obrobki budivelnih sumishej", *Visnik Harkivskogo nac. avtodor. un-tu*, vol. 57, pp. 59-62, 2012.

[13] O. Shkromada, A. Paliy, O. Yurchenko, N. Khobot, A. Pikhtirova, "Influence of fine additives and surfactants on the strength and permeability degree of concrete", *EUREKA: Physics and Engineering*, no. 2, pp. 19-29, 2020. doi.org/10.21303/2461-4262.2020.001178

[14] Kligys, Modestas & LAUKAITIS, Antanas, "The Influence of Some Surfactants on Porous Concrete Properties", *Materials Science*, vol. 13, no. 4, pp. 310-316, 2007.

[15] Linbo Jiang, Zhi Wang, Xueliang Gao, "Effect of nanoparticles and surfactants on properties and microstructures of foam and foamed concrete", *Construction and Building Materials*, vol. 411, 2024. doi.org/10.1016/j.conbuildmat.2023.134444

[16] Łaźniewska-Piekarczyk, Beata & Miera, Patrycja & Szwabowski, Janusz, "Plasticizer and Superplasticizer Compatibility with Cement with Synthetic and Natural Air-Entraining Admixtures", *IOP Conference Series: Materials Science and Engineering*, vol. 245, no. 3, 2017. doi.org/10.1088/1757-899X/245/3/032094

[17] Mehran Khan, Majid Ali, "Effect of super plasticizer on the properties of medium strength concrete prepared with coconut fiber", *Construction and Building Materials*, vol. 182, pp. 703-715, 2018. doi.org/10.1016/j.conbuildmat.2018.06.150

[18] Dzigita Nagrockiene, Ina Pundienė, Asta Kicaite, "The effect of cement type and plasticizer addition on concrete properties", *Construction and Building Materials*, vol. 45, pp. 324-331, 2013. doi.org/10.1016/j.conbuildmat.2013.03.076

[19] Nilforoushan, Mohammad, "The Effect of Micro Silica on Permeability and Chemical Durability of Concrete Used in the Corrosive Environment", *Iranian journal of chemistry & chemical engineering-international english edition*, vol. 24, no. 2, pp. 31-37, 2005. doi.org/10.30492/ijcce.2005.8122

[20] Rahman Md. Asifur & Zawad, Md. Fahad & Priyom Sudipto, "Potential use of microsilica in concrete: a critical review", *Conference: 5th International Conference on Advances in Civil Engineering (ICACE 2020).* Bangladesh: Chittagong University of Engineering & Technology, 2021.

[21] Ehsan Hosseinzadehfard, Behnam Mobaraki, "Investigating concrete durability: The impact of natural pozzolan as a partial substitute for microsilica in concrete mixtures", *Construction and Building Materials,* vol. 419, 2024. doi.org/10.1016/j.conbuildmat.2024.135491.

МЕХАНОАКТИВАЦІЯ ЗМІШАНОГО В'ЯЖУЧОГО ТА ЇЇ ВПЛИВ НА МІЦНІСТЬ БУДІВЕЛЬНОГО РОЗЧИНУ

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Анотація. Розглянуті у статті питання пов'язані з визначенням впливу механоактивації змішаного в'яжучого на властивості будівельного розчину. Дослідження полягало у частковій заміні цементу меленим кристалічним кварцовим піском та аморфним мікрокремнеземом (в подальшому МК) в поєднані з використанням суперпластифікатору Релаксол-Супер ПК (в подальшому СП). Кількість меленого піску корегувалася в діапазоні від 0 до 40%, МК від 0 до 10% та СП від 0 до 1% маси в'яжучого. Термін активації в'яжучого складав 180 сек. Застосування даної рецептури надає можливість підвищити міцність та знизити витрати портландцементу в технології виготовлення будівельного розчину.

Одержані експериментальні дані підтвердили вплив рецептурно-технологічних факторів на водотверде відношення цементно-вміщуючої композиції. Встановлено, що основний вклад в зниження водотвердого відношення (при умові одержання рівнов'язких композицій) надає механоактивація в сукупності із заміною 40% цементу меленим кварцовим піском і додаванням 1% СП. Водотверде відношення зменшується більше, ніж на 50%, що позитивно відображається на міцності розчину.

Зростання міцності будівельного розчину з доданням СП досягало 93% (на ранніх термінах тверднення) та 56% (у марочному віці) в порівнянні з контролем. Використання МК у складі будівельного розчину забезпечує відносно незначне зростання міцності (12%) на ранніх термінах тверднення та 8% у марочному віці в порівнянні з контролем.

Використання тільки механоактивації забезпечує зростання міцності розчину на 18% (на ранніх термінах тверднення) та 13% (у марочному віці) в порівнянні з контролем. Сумісна дія механоактивації, СП та МК у складі будівельного розчину компенсує негативний вплив меленого кварцового піску та позитивно відображається на зростанні міцності (до 38%), також забезпечуючи зниження витрати цементу на 40%.

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

Стаття надійшла до редакції 1.12.2024