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THE EFFECT OF MECHANICAL ACTIVATION OF MIXED PORTLAND CEMENT IN THE PRESENCE OF A SUPERPLASTICIZER ON THE COMPRESSIVE STRENGTH OF CEMENT STONE

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Abstract. The presented article provides experimental results related to determining the influence of mechanic activation of mixed Portland cement and a superplasticizing admixture on the physical and mechanical properties of cement stone under compression at the ages of 3, 7, and 28 days. Such cement was obtained by mixing Portland cement PC-I 500 with ground quartz sand, the amount of which varied within the range of 30–60 % of the total binder mass. A promising method for increasing the compressive strength of cement stone is intensive mechanic and chemical activation of mixed cement in a high-speed turbulent-type activator in the presence of a superplasticizer SP-5, the content of which varied from 0 to 1 % of the binder mass.

The research was carried out using D-optimal mathematical experimental design, with variation of the following factors: consumption of ground quartz sand (45 ± 15) % of the mixed binder mass and the amount of superplasticizing admixture (% of the mixed binder mass). The cement-water mixture was prepared using two technologies: the first with a high-speed activator (rotor speed 1500 rpm) and the second by traditional (control) mixing. The obtained mathematical models indicate a significant influence on the compressive strength of the cement stone by both the formulation factors (X_1, X_2) and the technological parameters of the mixing process. It should be noted that the combined effect of mechanic and chemical activation, the amount of ground sand, and the superplasticizer makes it possible to increase the compressive strength of the cement stone (compared to the control) by 22…41 %, which allows a substantial increase in the proportion of ground quartz sand in the mixed binder composition as a mineral additive to cement.

Keywords: mechanic activation, Portland cement, superplasticizer, mineral additive, compressive strength, variable factors.

Introduction. It is known that one of the key problems in the technology of production of mixed cements is the formation of optimal combinations of Portland cement with mineral additives, which allows to increase the potential properties of the binder. Quartz sands have become widespread as a mineral additive to cements, the presence of which in their composition ensures not only a reduction in the cost of the mixed binder, but also provides a number of positive properties to the cement stone (reduction of shrinkage, reduction of the magnitude of exothermic heating, etc.). The article considers the influence of mechanical and chemical activation of Portland cement, the amount of ground quartz sand and superplasticizer on the compressive strength of the cement stone. In our opinion, the combined use of ground quartz sand, superplasticizer, mechanical and chemical activation of the mixed binder contributes to obtaining cement stone with increased compressive strength.

Analysis of recent research and publications. One of the most common ways to reduce the cost of Portland cement is to introduce finely ground inert mineral additives, in particular, ground sand [1-5]. Technologically, such cement can be obtained both by joint grinding of Portland cement clinker, dihydrate gypsum and mineral additive, and by thorough mixing of Portland cement with ground mineral additive [6-9].

In works [10-15] it is convincingly shown that the effect of adding mineral additives to Portland cement is significantly enhanced in conditions of turbulent flows, which are achieved in the process of mechanical and chemical activation of mixed cement. In our opinion, the use of high-speed mixers for cement activation in combination with ground quartz sand and a superplasticizer will accelerate the cement hydration processes, which will allow to abandon both thermal and wet processing and the use of scarce rapid-setting cements.

Purpose and objectives. The above has determined the purpose of the study, which is to study the effect of mechanochemical activation of Portland cement with the addition of ground quartz sand (30–60 %) and superplasticizer SP-5 (0...1 %) on the compressive strength of cement stone after 3, 7 and 28 days.

Portland cement activation was carried out by intensively influencing the water-cement and cement-sand mixture (S_{sand} = 350 m^2/kg) in a high-speed turbulent mixer for 2 minutes. The use of a high-speed mixer contributes to the physicochemical activation of the surface layer of both fine grains of Portland cement and grains of ground quartz sand. The presence of activation ensures the intensification of cement hydration processes, which is reflected in the increase in the strength of the cement stone, especially in the early stages of hardening. The turbulent mixer is characterized by a high speed of rotation of the working body, which is 1500 rpm.

Materials and research methods. Experimental studies were conducted using Portland cement brand PC-I 500 of PJSC "Volyn Cement" as a binder. According to its properties, Portland cement meets the requirements of DSTU B.V.2.7-46:201 "Cements for general construction purposes. Technical conditions". Cement-sand binder was obtained by thoroughly mixing Portland cement and ground quartz sand, the consumption of which ranged from 30 to 60 % of the mass of the mixed binder. The specific surface area of ground quartz sand was taken to be 350m^2/kg. Plasticization of the mixture was carried out using superplasticizer SP-5, the consumption of which, as noted earlier in the text, ranges from 0 to 1 % of the mass of the mixed binder.

Research results. To determine the combined effect of mechanical activation, as well as the addition of ground quartz sand to cement and the consumption of superplasticizer SP-5 on the strength of cement stone at the age of 3, 7 and 28 days, a 2-factor experiment was conducted. The following were taken as independent variables: X_1 – consumption of ground quartz sand (45±15) % of the mass of the mixed binder; X_2 – amount of superplasticizing additive SP-5 (0.5±0.5) % of the mass of the mixed binder. The experimental conditions provided for obtaining for all rows of the mathematical plan mixtures with a spread diameter of 120 mm on the Suttord device (control), Table 1.

Table 1 – Experimental plan and component costs

№	Levels of variation		Consumption of cement dough components per batch, g				W/S	Spread of cement paste, mm	
			Portland cement, g	Ground sand, g	SP-5, g	Mixing water, g		Control	Mechanical activation
	X_1	X_2							
1	-1	-1	1400	600	0	757	0.38	122	139
2	-1	0	1400	600	10	672	0.34	120	145
3	-1	1	1400	600	20	623	0.31	120	156
4	0	-1	1100	900	0	736	0.37	119	137
5	0	0	1100	900	10	640	0.32	120	141
6	0	1	1100	900	20	582	0.29	118	151
7	1	-1	800	1200	0	720	0.36	120	136
8	1	0	800	1200	10	617	0.31	121	140
9	1	1	800	1200	20	579	0.30	122	148

Analysis of the experimental data given in Table 1, indicates that mechanical and chemical activation for 2 minutes of cement-containing compositions with the addition of ground quartz sand (45±15% of the mass of the mixed binder) contributes to an increase in the diameter of the spread of the mixture (compared to the control) by an average of 14…21 %.

The results of the compressive strength of cement stone at 3, 7, and 28 days of age for both the mechanically activated mixed binder and the binder that was not subjected to mechanical activation (control) are given in Table 2.

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

№	Levels of variation		Reviews					
			$R_{cs}^{c.}$, MPa			$R_{cs}^{m.}$, MPa		
	X_1	X_2	3 days	7 days	28 days	3 days	7 days	28 days
1	-1	-1	20.1	32.3	44.5	26.4	43.2	61.1
2	-1	0	24.2	36.6	51.2	33.5	48.2	68.2
3	-1	1	26	40.3	57.4	36.2	54.3	75.5
4	0	-1	15.8	23.4	33.9	20.3	32.7	45.6
5	0	0	18.5	28.5	40.1	24.6	36.9	51.2
6	0	1	21	32.1	46.1	29.7	42.4	60.4
7	1	-1	12.7	21.1	28.8	16.4	28.4	40.2
8	1	0	15.3	23.6	33.3	21.1	32.3	45.1
9	1	1	17.1	27.0	38.1	23.9	36.1	51.4

Note: $R_{cs}^{c.}$, – strength of cement stone on mixed binder, which was not subject to mechanical activation, MPa $R_{cs}^{m.}$, – strength of cement stone on mechanically activated mixed binder, MPa.

As a result of statistical processing of experimental data, mathematical models (1…6) were obtained, which with high probability (≥0,95) reflect the influence of the studied factors on the compressive strength of cement stone both on ordinary (non-mechanically activated) mixed binder (1-3) and on mechanically activated mixed binder (4-6):

$$R_{cs}^{c.3}\ (\text{MPA}) = 18.8 - 4.2\ X_1 + 0.8\ X_1^2 + 2.6\ X_2 - 0.6\ X_2^2 \quad (1)$$

$$R_{cs}^{c.7}\ (\text{MPA}) = 28.3 - 6.3\ X_1 + 2.2\ X_1^2 - 0.5\ X_1X_2 + 3.8\ X_2 - 0.2\ X_2^2 \quad (2)$$

$$R_{cs}^{m.28}\ (\text{MPA}) = 51.8 - 11.4\ X_1 + 4.5\ X_1^2 - 0.9\ X_1X_2 + 6.7\ X_2 + 0.9\ X_2^2 \quad (3)$$

$$R_{cs}^{m.3}\ (\text{MPA}) = 25.7 - 5.8\ X_1 + 1.4\ X_1^2 - 0.6\ X_1X_2 + 4.5\ X_2 - 0.9\ X_2^2 \quad (4)$$

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$$R_{cs}^{m.7}\ (\text{MPA}) = 37.1 - 8.2\ X_1 + 3.1\ X_1^2 - 0.9\ X_1X_2 + 4.8\ X_2 + 0.4\ X_2^2 \quad (5)$$

$$R_{cs}^{c.28}\ (\text{MPA}) = 40.0 - 8.8\ X_1 + 2.2\ X_1^2 - 0.9\ X_1X_2 + 6.1\ X_2 - 0.6\ X_2^2 \quad (6)$$

де: $R_{cs}^{c.3}$, $R_{cs}^{c.7}$, $R_{cs}^{c.28}$– compressive strength of cement stone on a mixed binder that was not subject to mechanical activation, MPa;

$R_{cs}^{m.3}$, $R_{cs}^{m.7}$, $R_{cs}^{m.28}$– compressive strength of cement stone on mechanically activated mixed binder, MPa.

Analyzing mathematical models (1…6), it should be noted that the content of ground sand in the mixed binder has a significant impact on the strength of cement stone both on mechanically activated mixed binder and on mixed binder that was not subjected to mechanical activation. An increase in the amount of ground sand in the mixed binder from 30 to 60 % (mechanical activation is absent) contributes to a decrease in the strength of cement stone from 44.5 MPa to 28.8 MPa, i.e. by almost 35 % (superplasticizer is absent). For cement stone on mechanically activated binder, an increase in the amount of ground sand from 30 to 60 % also causes a decrease in the strength of cement stone, but from 61.1 to 40.2 MPa. It should be determined that in this case, mechanical activation contributes to an increase in the strength of cement stone from 28.8 MPa (control) to 40.2 MPa, i.e. more than 28%. The combined use of mechanical activation and 1% superplasticizer ensures the obtaining of a compressive strength of cement stone at 28 days of age of 75.5 MPa (with 60 % ground sand in the mixed binder), i.e. almost 24 % higher compared to the control.

Considering the influence of variable factors on the compressive strength of cement stone, it should be noted that mechanical activation of mixed cement in combination with the use of superplasticizer SP-5 allows changing the compressive strength of cement stone in a wide range at 3, 7 and 28 days of age.

A graphical representation of the influence of factors X_1 and X_2 on the strength of cement stone at 28 days of age is shown in Fig. 1.

Table 3 and Table 4 show the values of the factors X_1 and X_2, which provide the greatest strength of the stone in the studied stone (28 days).

Analysis of the influence of the formulation factors X_1 and X_2 on the strength of the stone on the binder, which was subjected to mechanical activation and non-mechanically activated binder (control) shows that by changing the influencing factors (mechanochemical activation, consumption of ground quartz sand and concentration of superplasticizer) it is possible to regulate the compressive strength of the cement stone at 28 days of age in the range from 25.8 (control) to 74.5 MPa.

The experimental results obtained indicate that:

a) mechanical and chemical activation of the aqueous cement-containing composition with the addition of ground quartz sand (45±15 %) provides an increase in the diameter of the spread of the mixture by an average of 14…21 % (compared to the control);

b) activation of mixed Portland cement in the presence of superplasticizer SP-5 (1 %) provides an increase in the strength of cement stone in the studied period of time (3, 7 and 28 days) on average by 2.5….2.9 times (compared to the control).

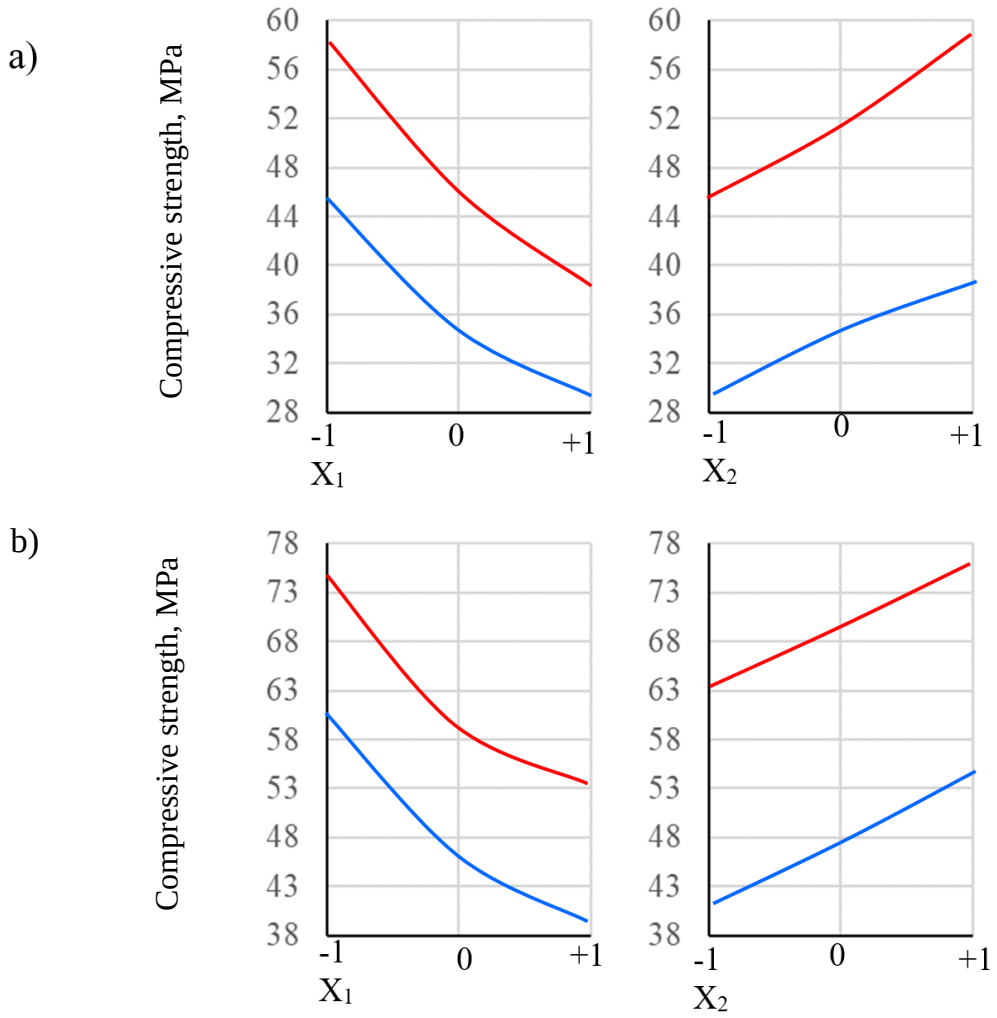

Fig. 1. Strength of cement stone at 28 days of age in the zone of maximum and minimum depending on the factors X_1 and X_2:
а – control-mixed binder that was not subject to mechanical activation; б – mixed mechanically activated binder. —— – zone of maximum strength; —— – minimum strength zone

Table 3 – Values of recipe factors X_1, which are responsible for the maximum and minimum strength (MPa) of cement stone

	Mechanical activation of the binder is absent (control) at the age of 3, 7 and 28 days of hardening								
	3 days		R_{cs}^{3}	7 days		R_{cs}^{7}	28 days		R_{cs}^{28}
	X_1	X_2		X_1	X_2		X_1	X_2	
min	+1	-1	12.6	+1	-1	20.7	+1	-1	25.8
max	-1	+1	26.2	-1	+1	40.9	-1	+1	55.6

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Table 4 – Values of recipe factors X_2, which are responsible for the maximum and minimum strength (MPa) of cement stone

	Mechanically activated binder at 3, 7 and 28 days of hardening								
	3 days		R_{cs}^3	7 days		R_{cs}^7	28 days		R_{cs}^{28}
	X_1	X_2		X_1	X_2		X_1	X_2	
min	+1	-1	16.5	+1	-1	28.5	+1	-1	39.9
max	-1	+1	37.1	-1	+1	54.5	-1	+1	74.5

Conclusions. The combined effect of activation of Portland cement and the addition of quartz sand with a specific surface area of 350 m^2/kg in an amount of 30 to 60 % of the mass of the mixed binder and the addition of superplasticizer SP-5 is an effective recipe-technological effect that provides a significant increase in the compressive strength of cement stone both at an early age (3 days) and at a more mature age (28 days). The combined use of mechanical activation and superplasticizer SP-5 significantly eliminates the loss of strength of cement stone due to the use of ground sand additives to cement in an amount of 30 to 60 %.

References

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

[2] R.F. Runova, V.I. Hots, M.A. Sanytskyi ta in., *Konstruktsiini materialy novoho pokolinnia ta tekhnolohii yikh vprovadzhennia v budivnytstvo*. K.:UVPK «EksOb». 2008.

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

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

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

[6] M.A. Sanytskyi, T.P. Kropyvnytska, O.V. Rykhlitska, O.B. Yanitskyi, "Shvydkotverdnuchi klinker-efektyvni betony", *Resursoekonomni materialy, konstruktsii, budivli ta sporudy: zb. nauk. prats*, vyp. 38, pp. 258-266, 2020.

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

[8] M.A. Sanytskyi, O.R. Pozniak, I.I. Kirakevych, N.I. Topylko, "Suchasni betony na osnovi kompleksnykh modyfikatoriv novoi heneratsii", *Budivelni materialy, vyroby ta sanitarna tekhnika*, no. 2(29), pp. 98-102, 2008.

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

[10] H. Khainike, *Trybokhimiia*. Pereklad z nim. 1987.

[11] I.V. Barabash, D.O. Pirohov, "Aktyvatsiia tsementu i yii vplyv na strukturoutvorennia tsementnovmishchuiuchykh kompozytsii", *Suchasne budivnytstvo ta arkhitektura*, vyp. 6, pp. 82-89, 2023.

[12] 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.

[13] I.V. Barabash, I.M. Babii, K.O. Streltsov, "Intensive separate technology and its influence on the properties of cement-water compositions, solutions and concretes on their basis", *Modern construction and architecture*, Issue no. 2, pp. 44-51, 2022.

[14] V.N. Vyrovov et al., *Mekhanicheskaya aktivatsiya v tekhnologii betona*. OGASA. 2014.
[15] L.I. Dvorkin, O.L. Dvorkin, *Proektuvannia skladiv betoniv*. Monohrafiia. Rivne: NUVHP, 2015.

ВПЛИВ МЕХАНОАКТИВАЦІЇ ЗМІШАНОГО ПОРТЛАНДЦЕМЕНТУ В ПРИСУТНОСТІ СУПЕРПЛАСТИФІКАТОРУ НА МІЦНІСТЬ НА СТИСК ЦЕМЕНТНОГО КАМЕНЮ

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Анотація. В розглянутій статті приводяться експериментальні результати, які пов'язані з визначенням впливу механоактивації змішаного портландцементу та суперпластифікуючої добавки $SP-5$ на фізико-механічні харектиристики цементного каменю на стиск у віці 3-х, 7-и та 28-и діб. Такий цемент отримували змішуванням портландцементу ПЦ-І 500 з меленим кварцовим піском ($S = 350\ м^2/кг$), кількість якого коливалася в діапазоні від 30 до 60 % в'яжучого. Перспективним способом підвищення міцності цементного каменю на стиск є інтенсивна механохімічна активація змішаного цементу у швидкісному активаторі турбулентного типу за присутності суперпластифікатора *SP-5*, вміст якого змінювався в межах від 0 до 1 % маси в'яжучої речовини.

Дослідження здійснювали із застосуванням D-оптимального математичного планування експерименту з варіюванням наступних факторів: X_1 – витрата меленого кварцового піску (45±15) % від маси комбінованого в'яжучого матеріалу; X_2 – кількість суперпластифікуючої добавки $SP-5$ – $(0{,}5 \pm 0{,}5)$ % маси змішаного в'яжучого. Приготування цементно-водної суміші проводилося за двома технологіями ,а саме: першої – з використанням швидкісного активатору з кількістю обертів ротору 1500 об/хв і другої , традиційної (контроль). Отримані математичні моделі вказують на суттєвий вплив на міцність цементного каменю як рецептурних факторів (X_1, X_2), так і технологічних параметрів процесу приготування суміші. Зокрема слід відзначити, що сумісний вплив механохімічної активації, витрати меленого піску та суперпласифікатору дозволяє підвищити міцність цементного каменю в (в порівнянні з контролем) на 22…41 %), що дає змогу суттєво збільшити частку меленого кварцового піску у складі змішаного в'яжучого як мінеральної добавки до цементу.

Ключові слова: механоактивація, портландцемент, суперпластифікатор, мінеральна добавка, міцність на стиск, фактори варіювання.

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