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THE INFLUENCE OF TECHNOLOGICAL FACTORS ON THE PROPERTIES OF REACTION POWDER CONCRETES BASED ON ALKALI-ACTIVATED SLAG PORTLAND CEMENT

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Abstract. The development of reactive powder concrete (RPC) based on Portland cements containing varying amounts of granulated blast furnace slag and activated with soluble sodium silicates is of global importance in terms of protecting critical infrastructure.

The article identifies factors influencing the kinetics of strength gain, inherent shrinkage deformation and impact strength of reactive powder concretes when using sodium metasilicate pentahydrate as an alkaline activator in various aggregate states (powder, solution), as well as soluble sodium silicates with a silicate modulus of M_s = 2...3. It has been shown that changing the ratio between slag portland cement and sand from 1:3 to 1:1 and using sodium metasilicate in powder form ensures the production of sand concrete with compressive strengths of 35.7, 63.8, 87.5, 118. 1 and 123.9 MPa after 1, 3, 28, 180 and 360 days, respectively.

The use of sodium metasilicate in the form of an aqueous solution significantly accelerates the kinetics of strength gain and provides a strength of 52.3, 85.0, 108.7, 126.1 and 141.1 MPa after 1, 3, 28, 180 and 360 days, respectively.

The introduction of finely dispersed calcite reduced the shrinkage during drying of RPC by 1.2...1.6 times. Reducing the OPC content from 45 to 5% by mass with a water silicate glass modulus of 2.6...2.7 resulted in a slight decrease in the early compressive strength of ultra-rapid hardening RPC, but provided a significant increase in the compressive strength limit from 112.5 MPa to 132.4 MPa after 28 days. Viscous fracture after 28 days is confirmed by a better brittleness coefficient of 5.3...5.9 and 10.5...28.7% higher impact toughness of samples on sodium metasilicate and sodium disilicate compared to the analogue based on OPC. RPC with stable long-term strength, high impact toughness and reduced shrinkage during drying has been obtained. The introduction of bleaching agents in the form of $CaCO_3$ and mineral pigments allows decorative RPC to be obtained.

The possibility of obtaining products by extrusion based on alkali-activated RPC with the determination of the main technological parameters of the process is indicated.

Keywords: reaction powder concretes, alkali-activated cement, strength, shrinkage.

INTRODUCTION

Current trends in materials science, as well as the military-political situation in the world and in Ukraine in particular, are leading to growing interest in high-performance concretes with increased resistance to dynamic loads [1-3]. One type of new-generation concrete is reactive powder concrete (further RPC) [4, 5].

The effectiveness of RPC for critical structures has been confirmed [6, 7].

RPC is characterised by high compressive and flexural strength (150...230 MPa and 20...50 MPa after 28 days) [8], crack resistance [9], corrosion resistance [10] and heat resistance [11].

However, despite the undeniable advantages of RPC, questions remain regarding its economic efficiency due to the high content of binder (about 1000 kg/m³), the total cost of production, the shortage of some raw materials and the insufficient study of the technological parameters of its production [6]. RPC requires a high level of production technology and hardening before commissioning [12]. The high binder content and the absence of coarse aggregate emphasise the relevance of significant shrinkage [13]. Another disadvantage of such concretes is their insufficient environmental friendliness. To partially overcome these disadvantages, it is recommended to replace cement (up to 50% by mass) or silica (10…15% by mass) with additional materials such as limestone, various slags, fly ash, glass powder, etc. [14].

The most promising for obtaining reaction-powder concretes are binding compositions obtained by alkali activation of cements containing up to 95% granulated blast furnace slag in accordance with EN 197-1:2011. Alkali-activated slag cements according to DSTU B V.2.7-181:2009 [15] are effective in reducing clinker content and, consequently, CO_2 emissions, as well as minimising the use of natural raw materials and energy resources [16, 17]. The most effective activators of alkali-activated cements (further, AAC) are sodium silicates, whose anions are similar to the hydrated primary decomposition products of the alumina-silica-oxygen framework and act as their additional reserve [18].

The use of alkali-activated cements in concrete and mortar, in addition to high strength, provides high heat resistance [11], sulphate resistance [19], frost resistance [20, 21], durability in marine environments [22], and crack resistance [23].

However, along with their advantages, AAC-based materials also have certain characteristics. One of them is greater shrinkage compared to Portland cements, which is explained by the increased content of gel-like and submicroscopic crystalline phases in hydration products, as well as the absence of crystalline phases such as portlandite $Ca(OH)_2$ and ettringite $3CaO{\cdot}Al_2O_3{\cdot}3CaSO_4{\cdot}32H_2O$ [18]. This feature exacerbates the problem of controlling shrinkage deformations in RPC. A well-known approach to reducing shrinkage in AAC is the use of mineral additives (limestone, fly ash, silica fume), chemical additives (shrinkage reducers, expanders, surfactants, superabsorbent polymers, nanoparticles), as well as various types of fibres (steel fibres, polypropylene fibres, carbon fibres, glass fibres) [24-28].

The aim of the study was to determine the influence of technological factors on the long-term physical and mechanical properties of alkali-activated reactive powder concrete based on slag Portland cement, including its compressive strength and impact toughness, as well as shrinkage during drying.

RAW MATERIALS AND TESTING TECHNIQUES

The following components were used in the AAC:

– Crushed granulated blast furnace slag (further – GBFS) (oxides, % by weight: CaO – 50.98; SiO_2 – 32.13; Al_2O_3 – 11.48; Fe_2O_3 – 0.4; MgO – 1.14; K_2O+Na_2O – 0.77; SO_3 – 1.8; LOI – 1.3), specific surface area (S) = 400 м^2/kg (according to Blaine), basicity modulus M_b = 1.18, glass phase content – 84.0 %.
– CEM I 42,5 N (further – OPC) (oxides, % by weight: CaO – 65.0; SiO_2 – 21.0; Al_2O_3 – 5.6; Fe_2O_3 – 4.8; MgO – 2.5; SO_3 – 0.7; K_2O+Na_2O – 0.15; LOI – 0.25) for EN 197-1:2011, specific surface area (S) = 390 м^2/kg (according to Blaine).
– Sodium metasilicate pentahydrate was used as the alkaline component. ($Na_2O{\cdot}SiO_2{\cdot}5H_2O$) for CAS 497-19-8 in both solid aggregate form (non-hygroscopic powder) and as a solution with a density of 1.24 g/ml; as well as high-modulus soluble sodium glass with M_s = 2...3.

As small aggregates in RPC used:

- Silicon river sand with non-optimised granulometry: 0…0.16 mm – 13.1%, 0.16…0.315 mm – 65.0%, 0.315…0.63 mm – 16.0%, 0.63…1.25 mm – 5.1%, 1.25…2.5 mm – 0.6%; Sand size module M_{ss} = 1.16.
- Silicon sand with optimised granulometry: fraction 0.315 mm – 22.47%, fraction 0.63 mm – 32.36%, fraction 1.25 mm – 45.17%, which was optimised by approximating the general granulometric curve to the ideal Fuller curve [29-31], which ensures minimal intergranular voids. The fraction that passed through a 0.16 mm sieve was not used.

To control shrinkage during drying, finely dispersed calcium carbonate (*$CaCO_3$*) per CAS 471-34-1 was used in the RPC.

The RPC was prepared in a standard Hobart mixer.

The strength of cement-sand mortars was determined on beam samples measuring 4×4×16 cm with a composition of 1:1, 1:2, and 1:3 (binder : sand) and on 10×10×10 cm cube samples using quartz river sand with M_{ss} = 1.16. Strength was determined after 1, 2, 3, 7, 28, 90, 180, and 360 days.

The RPC impact strength (impact toughness) test was performed according to the method described in [32]. The concrete impact strength test scheme is shown in Fig.1.

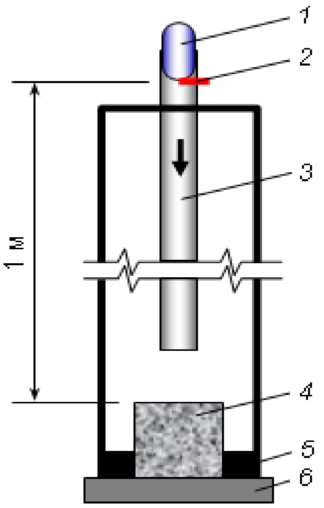

Fig. 1 Concrete impact strength test procedure: *1* – 2 kg weight; *2* – weight lock; *3* – vertical guide pipe; *4* – 10×10×10 cm concrete cube sample; *5* – sample position lock; *6* – solid foundation

Рис. 1 Схема випробування бетону на ударну міцність: *1* – гиря вагою 2 кг; *2* – фіксатор гирі; *3* – направляюча вертикальна труба; *4* – куб-зразок бетону 10×10×10 см; *5* – фіксатор положення зразка; *6* – масивна основа

The viscosity (crack resistance) of concrete was evaluated based on the ratio of compressive strength to flexural tensile strength.

Shrinkage deformations of fine-grained concrete were determined on samples measuring 40×40×160 mm. After fabrication and hardening in molds with an insulated surface for 24 hours, the samples were removed from the molds and stored for 7 days under normal conditions (t = 20±2°C, R.H. = 95±5%). The samples were then stored above a saturated solution of ammonium nitrate (*NH_4NO_3*) at t = 20±2°C and R.H. = 65% until the control age. The length of the samples after 1 day was taken as the initial (zero) length.

RESULTS AND DISCUSSIONS

As a cementitious matrix for RPC, AACs based on sodium metasilicate (*system 1*) and soluble high-modulus glass (*system 2*) were investigated. System 1 was considered in terms of obtaining RPC as a single-component product [33, 34, 35], while system 2 was used to obtain ultra-fast-setting RPC [18, 36].

RPC based on AAS system 1

The effect of the AAC to sand ratio on the strength of RPC was studied using siliceous sand with non-optimized granulometry (Table 1). Sodium metasilicate was used in a solid aggregate state (powder). The compositions were mixed with water.

Table 1 Physical and mechanical characteristics of fine-grained alkali-activated concretes depending on the ratio of "binder : sand"

Табл. 1 Фізико-механічні характеристики дрібнозернистих лужно-активованих бетонів залежно від співвідношення "в'яжуча речовина : пісок"

Compositions of AAC, wt. %			AAC-to-sand ratio	Water-to-AAC ratio	Consistency (flow), mm	Compressive strength / flexural strength, MPa, at age, day							
GBFS	OPC	sodium metasilicate				1	2	3	7	28	90	180	360
85	5	10	1:1	0.218	180	35.7 / 5.9	55.1 / 6.7	63.8 / 7.4	73.6 / 10.5	87.5 / 14.8	104.5 / 17.9	118.1 / 19.8	123.9 / 20.7
			1:2	0.237	165	27.1 / 6.0	42.8 / 7.1	50.7 / 8.8	57.7 / 9.2	67.7 / 11.0	78.5 / 13.0	88.5 / 15.5	92.6 / 16.3
			1:3	0.334	145	20.7 / 5.6	31.4 / 5.8	35.7 / 6.1	42.4 / 8.3	49.8 / 10.5	57.0 / 12.5	61.7 / 14.7	64.8 / 15.4

As can be seen in Fig.2, the dependence of strength on sand content is practically linear under the condition of Water-to-AAC ratio ≤ 0.35.

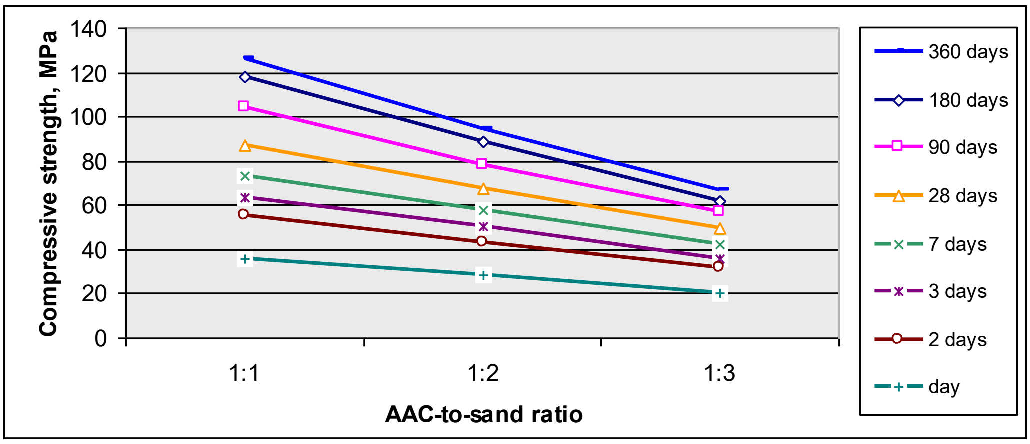

Fig. 2 Dependence of the strength of cement-sand concretes at different hardening times on the ratio of "binder : sand". Alkaline component – sodium metasilicate

Рис. 2 Залежність міцності цементно-піщаних бетонів у різні строки твердіння від співвідношення "в'яжуче : пісок". Лужний компонент – метасилікат натрію

As can be seen from the results in Table 1 and Fig. 2, an increase in the binder content in the composition leads to an expected increase in strength. The highest strength was demonstrated by the composition with a "binder : sand" ratio of 1:1 (see Table 1), which is accepted for further research as RPC.

The effect of the aggregate state of sodium metasilicate on the strength of RPC was studied at a ratio of AAS to sand of 1:1. Siliceous sand with optimized granulometry was used. According to previous studies, the use of such sand increases strength by 7…8% due to denser packing of aggregate grains and a reduction in water content for standard consistency according to EN 196-3, which is associated with a decrease in the specific surface area of the aggregate [35].

Sodium metasilicate was added in equal amounts – 10.0% (in terms of dry matter) or 2.9% (in terms of Na_2O).

The genesis of RPC strength with different Portland cement contents in the cement-slag mixture when using sodium metasilicate in different aggregate states is shown in Fig.3.

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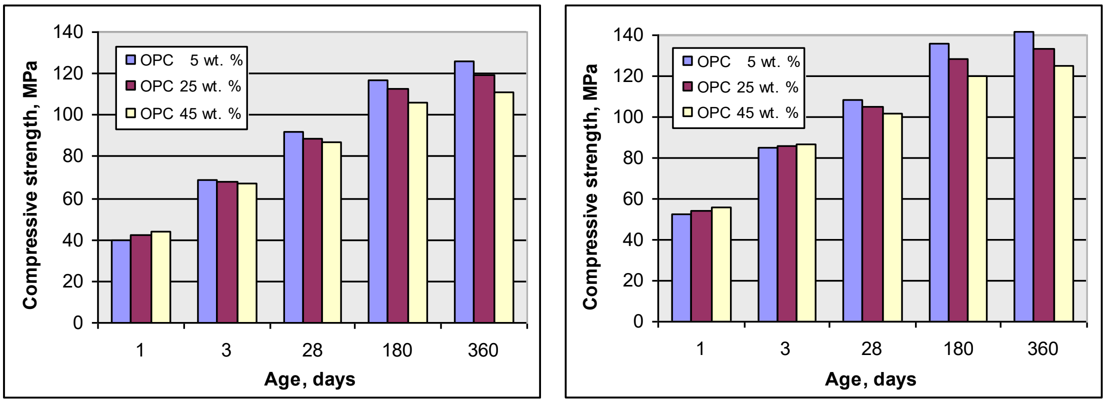

a *b*

Fig. 3 Strength of RPC depending on age and aggregate state of sodium metasilicate: *a* – solid aggregate state (powder); *b* – liquid aggregate state (solution);

Рис.3 Міцність RPC залежно від віку та агрегатного стану метасилікату натрію: *а* – твердий агрегатний стан (порошок); *б* – рідинний агрегатний стан (розчин)

The use of sodium metasilicate in solution form instead of dry powder ensured maximum reduction in the soluble-binding ratio, which led to a further intensification of concrete strength development by 30.5%, 23.5%, 18.4%, 6.1%, and 3.9%, providing 52.3, 85.0, 108.7, 136.1, and 141.4 MPa at ages 1, 3, 28, 180, and 360 days, respectively.

All compositions showed a stable and monotonous increase in long-term strength, which contradicts the conclusions presented in [37].

The brittleness coefficient was 5.3...5.5, 5.5...5.7, and 5.7...6.0 at 28, 90, and 360 days, respectively, indicating a sufficiently high crack resistance of RPC [38].

The setting times of the compositions using sodium metasilicate powder and a Portland cement content of 5…45% in the slag cement mixture were 19…100 min, and with the addition of 2% LSTM additive, they were 40…118 min. An increase in the Portland cement content causes a reduction in setting times.

The effect of the OPC content in the "GBFS + OPC" mixture on the shrinkage of RPC during drying was investigated using a complete factorial design of type 2^3 [39]. Shrinkage during drying is a critically important characteristic of concrete in general and RPC in particular [40-42]. To ensure a comprehensive effect on shrinkage reduction, $CaCO_3$ additive was used, the positive effect of which in alkali-activated systems was demonstrated in [27, 35].

The following variables were selected: X1 – $CaCO_3$ content (0...40 wt.%); X2 – OPC content in AAC (5...45 wt.%). The study was conducted with a 1:1 ratio of AAC to sand. The content of sodium metasilicate in the solid state (powder) was 10.0 %. As a result of mathematical processing of the experimental results, adequate regression equations were obtained. Based on the obtained regression equations, a response surface of shrinkage change during RPC drying was constructed (Fig. 4).

Increasing the OPC content from 5 to 45 % by mass and the $CaCO_3$ content from 0 to 20...25 % by mass made it possible to reduce the shrinkage of RPC from 1.23 mm/m to 0.50...0.55 mm/m (by 55...60 %).

In addition, $CaCO_3$ can be considered a whitening additive, so adding it in the optimal amount (20...25 %) allows the resulting RPC to be classified as white and decorative, with a whiteness level of at least 70 %.

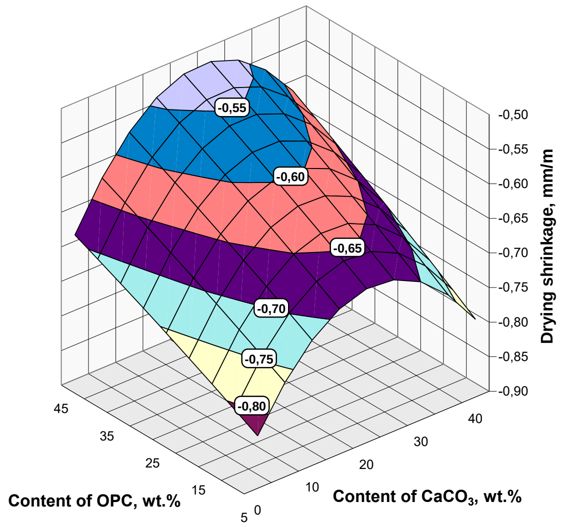

Fig.4 Drying shrinkage of RPC at 90 days vs. content of OPC vs. content of $CaCO_3$

Рис.4 Усадка RPC при висиханні на 90 добу залежно від вмісту OPC та вмісту $CaCO_3$

The effect of sodium silicates on the impact strength of RPC was studied using a composition based on AAC with an "OPC : GBFS" ratio of 5 : 95 (compositions #1 and #2). Sodium metasilicate and sodium disilicate were used in a solid aggregate state (powder). RPC based on CEM I 42.5 R with a superplasticizer (composition #3) was used as a comparison analogue. All compositions were mixed with water. The test results are presented in Fig. 5 and Fig. 6. The samples are cubes measuring 10×10×10 cm. The samples were tested at 28 days and 180 days.

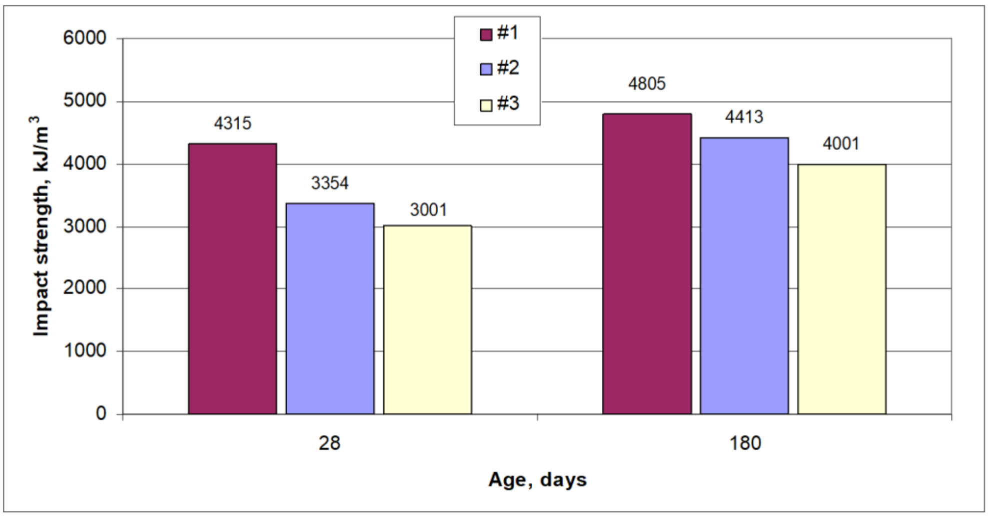

Fig. 5. Dependence of RPC impact strength on RPC composition and age: #1 - RPC based on AAS with sodium disilicate, #2 - RPC based on AAS with sodium metasilicate, #3 - RPC based on OPC (control)

Рис. 5. Залежність ударної в'язкості RPC від складу RPC та віку: #1 - RPC на основі ААС з дисилікатом натрію, #2 - RPC на основі ААС з метасилікатом натрію, #3 - RPC на основі OPC (контроль)

As can be seen in Fig. 5, composition #1 based on sodium disilicate demonstrated the highest impact strength. Slightly lower was #2 based on metasilicate. And the lowest was #3 based on OPC (sample for comparison). Fig. 6 also shows that sample *c* based on Portland cement is more brittle, as fragments of the sample broke off, while samples *a* and *b* only developed cracks.

The nature of destruction and higher impact resistance indicators of RPC based on alkali-activated slag Portland cements can be explained by the peculiarities of the phase composition of new formations with a predominance of low-base calcium hydrosilicates and mixed *Na-Ca* composition, the ratio of gel-like and crystalline components of hydraulic new formations with a predominance of the gel-like component [43], which is confirmed by other authors [9, 33]

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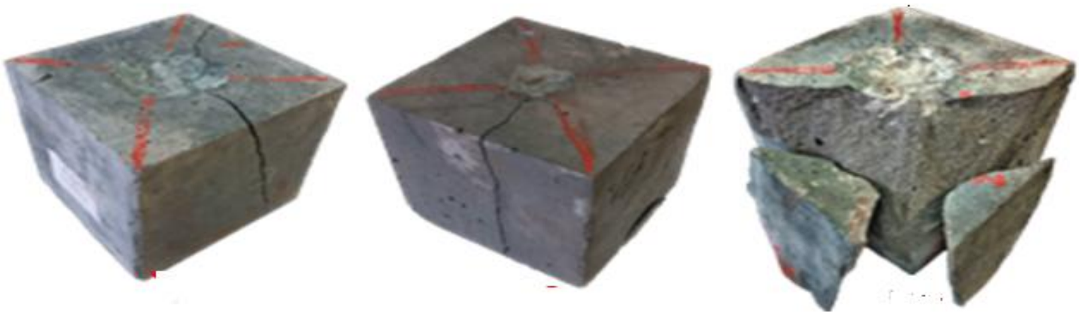


a *b* *c*

Fig. 6. Samples of reaction-powder concretes of different compositions after impact resistance testing after 28 days of hardening: *a* – RPC based on AAC with sodium disilicate, *b* – RPC based on AAC with sodium metasilicate, *c* – RPC based on OPC (control)

Рис. 6. Зразки реакційно-порошкових бетонів різного складу після випробування на ударна стійкість через 28 діб тверділня: *а* – RPC на основі AAC з дисилікатом натрію, *б* – RPC на основі AAC з метасилікатом натрію, *в*– RPC на основі традиційного портландцементу (контроль)

In addition, concretes of this class have higher adaptive properties and the ability to self-heal defects in the form of cracks if they appear as a result of extreme operating conditions [36].

Regardless of the composition, the impact strength of all RPBs increases over time [34, 35].

RPC based on AAS system 2

The influence of the silicate modulus of soluble glass on the strength of RPC was studied using a complete factorial design of experiment type 2^3. High-modulus sodium glass (density 1.3 g/cm³) was used. Trisodium phosphate (further TNF) was added to the soluble glass in an amount of 12% of the mass of sodium glass. The ratio of AAS to sand was 1:1. Siliceous sand with optimized granulometry was used. The factors, their variation levels, and the results of the experiment are presented in Table 2 and Table 3.

Table 2 Initial data

Табл. 2 Вихідна дані

Factors	Units of measurement	Code	Levels of variation		
			–1	0	+1
Silicate modulus of glass, Ms	–	X1	2	2.5	3
OPC content in the mixture	%	X2	5	25	45

Table 3. Experiment plan and results

Табл. 3. План і результати експерименту

N	Plan matrix in co-codes		Plan matrix in natural values		Compressive strength, R compression, MPa, through							
	X1	X2	M_s	OPC %	3 hours	1 day	3 days	7 days	28 days	90 days	180 days	360 days
1	+1	+1	3	45	26.9	45.7	66.2	82.8	96.6	102.7	105.3	109.5
2	+1	-1	3	5	24.1	40.0	62.4	89.8	119.3	126.7	129.9	134.1
3	-1	+1	2	45	21.1	36.2	53.2	66.4	77.7	82.7	84.8	88.2
4	-1	-1	2	5	19.0	32.1	50.4	72.1	91.1	96.8	99.3	102.9
5	+1	0	3	25	25.5	40.9	64.4	86.3	108.1	114.9	117.8	121.7
6	-1	0	2	25	20.1	32.0	51.9	69.2	84.5	89.8	92.1	95.7
7	0	+1	2.5	45	28.0	45.4	69.2	88.9	111.9	118.9	121.9	125.8
8	0	-1	2.5	5	25.6	40.7	65.9	95.3	129.8	138.0	141.5	144.6
9	0	0	2.5	25	26.8	40.8	67.6	92.1	121.0	128.6	131.8	136.1

As a result of processing the data in Table 4, regression equations were obtained for all hardening times, which adequately describe the results of the experiment.

$$R_1 = 40.899 + 4.383 \cdot X_1 + 1.657 \cdot X_2 - 9.483 \cdot X_1^2 + 2.117 \cdot X_2^2 + 0.4 \cdot X_1 \cdot X_2 \ (R^2 = 0.99) \quad (1)$$

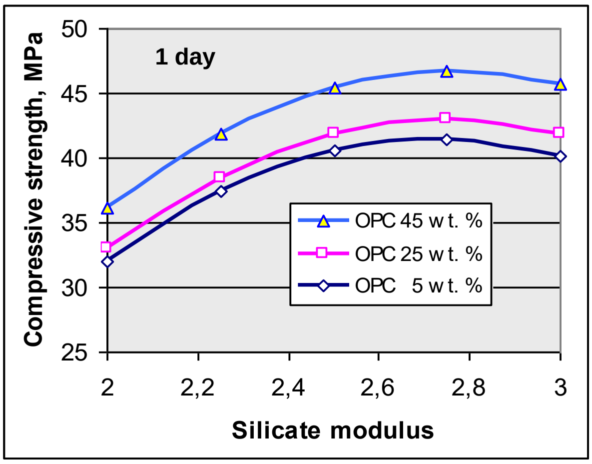
$$R_{28} = 120.989 + 11.783 \cdot X_1 - 9 \cdot X_2 - 24.683 \cdot X_1^2 - 0.133 \cdot X_2^2 - 2.325 \cdot X_1 \cdot X_2 \ (R^2 = 0.99) \quad (2)$$

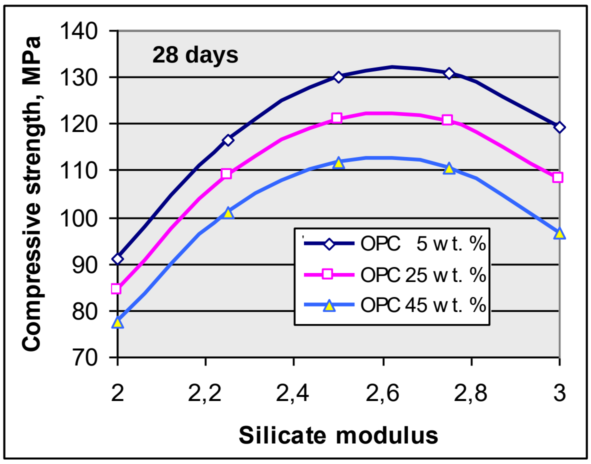
$$R_{360} = 132.633 + 13.083 \cdot X_1 - 9.167 \cdot X_2 - 24.35 \cdot X_1^2 - 0.6 \cdot X_2^2 - 2.475 \cdot X_1 \cdot X_2 \ (R^2 = 0.99) \quad (3)$$

Based on the regression analysis of the equations, it was concluded that in the early stages of hardening (up to 3 days inclusive), both factors have a positive effect on strength – equation (1). Moreover, the influence of factor X1 (Ms) is slightly stronger than that of X2 (OPC content).

Subsequently, the picture changes somewhat. Starting from 7 days onwards, the influence of factor X1 (Ms) remains positive, while the influence of factor X2 (ORP) changes to the opposite, i.e., it no longer contributes to an increase in strength—equations (2) and (3).

As a result, it was shown that the use of soluble sodium silicates with M_s = 2...3 ensured the production of ultra-fast-setting high-strength reaction-powder concretes with compressive strength after 3 hours of 19.0...28.0 MPa, 1 day – 32.1…45.7 MPa, after 7 days – 66.4…95.3 MPa, after 28 days – 77.7…129.8 MPa, after 90 days – 82.7… 138 MPa, after 180 days – 84.8…141.5 MPa, 360 days – 88.2…144.6 MPa (Table 3). The optimal solution is to use soluble sodium glass with Ms = 2.6…2.7 (Fig. 7).





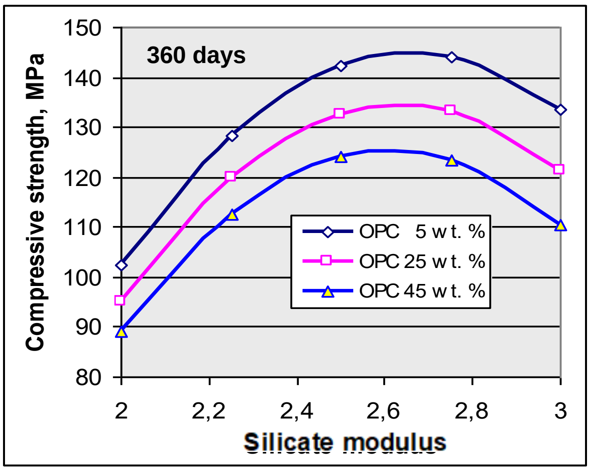


Fig. 7. The influence of the silicate modulus of soluble glass and the composition of alkali-activated slag Portland cements on the strength of RPC after 1, 28, and 360 days of hardening. The density of the solution is 1.35 g/cm^3, and the TNF content in the solution is 12%

Рис. 7 Вплив силікатного модуля розчинного скла та складу лужно-активованих шлакопортландцементів на міцність RPC через 1, 28 та 360 діб твердіння. Густина розчину – 1.35 г/см^3, вміст ТНФ у розчині – 12%

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At the same time, the strength ratio "compression : bending" was 5.8 on day 28 and 6.2 after 90 days for the optimal composition with the content of OPC in the mixture "GBFS + OPC" – 5% and M_s = 2.5 (Table 3, item 8), which indicates a sufficiently high impact strength and crack resistance of concrete.

The setting times were 34…46 minutes, but they can be increased to 60…90 minutes by using the complex additive "TNF + glycerin".

Based on the method of absolute volumes of raw components of the concrete mixture, the composition of the RPB per 1 m^3 was calculated with a ratio of "binder : sand" of 1:1 using a powdered alkali component and mixing the concrete with water:

– binding agent (slag + Portland cement + alkali component) – 1034 kg/m^3;
– fine river sand (M_{ss} = 1.16) – 1034 kg/m^3;
– water – 220…230 l/m^3 (W/C = 0.213…0.222).

Despite the low W/C ratio, the mixture was fairly easy to lay – the spread on the vibrating table after 30 strokes was 210…220 mm.

The composition was designed taking into account that it would be subjected to vibration during laying and that the air content would not exceed 4…8% by volume.

The option of using RPC for forming products by extrusion or using them in 3D-printers with the determination of the main technological parameters of the process was also considered.

The concrete mixture *extrusion method* is used to manufacture formwork-free products (pipes, panels, floor slabs, blocks, etc.) when the mixture is extruded through a forming head. For this process, concrete must have *special rheological properties* – sufficient plasticity for forming, but at the same time high rigidity so that the product retains its shape after leaving the mold. It has been established that when using RPC based on alkali-activated slag Portland cements, the cone slump should be 1…4 cm (stiffness 7…12 sec.) depending on the volume and configuration of the product, the type of extruder (screw, screw-auger), the pressure and speed of extrusion of the mixture. More specific pressure and speed values vary with the type of extruder. Therefore, follow the equipment instructions and perform a series of routine test mouldings. Fast-setting mixtures with a setting time of 25…40 minutes are recommended.

RPC mixtures for 3D-printing must have the following key characteristics: Suttard spread 12…15 cm, water retention ≥ 97%, setting time ≤ 20 min.

CONCLUSIONS

1. Stable long-term properties of rapid-hardening, high-strength "GBFS+OPC"-based alkali-activated RPC were achieved by regulating the aggregate state and silicate modulus of soluble sodium silicates, which represent the key technological factors.
2. The use of sodium metasilicate in the form of a solution instead of dry powder ensured the maximum reduction in the soluble-binding ratio, which led to a further intensification of concrete strength development by 30.5%, 23.5%, 18.4%, 6.1%, and 3.9%, ensuring a strength of 52.3, 85.0, 108.7, 136.1, and 141.4 MPa at ages 1, 3, 28, 180, and 360 days, respectively. The ratio of compressive strength to flexural strength in the range of 5.3...5.9 confirmed the high viscosity and crack resistance of concrete..
3. Adding calcite ($CaCO_3$) to RPC in optimal amounts reduced shrinkage during drying at the moment of its stabilization by 1.2...1.6 times, which is explained by a denser microstructure and more intense crystallization processes of hydration products.
4. It has been shown that RPC based on alkali-activated slag Portland cements demonstrate higher ballistic characteristics compared to RPC based on traditional Portland cement.
5. A specific feature of the influence of the age factor on the obtained RPC is stable long-term strengthening. Thus, RPC based on AAC with sodium metasilicate and soluble glass demonstrates increased values of key properties compared to 28-day age: compressive strength after 360 days – up to 141.4 MPa (by 30.1%) and 144.6 MPa (by 9.1%); impact strength after 180 days – up to

4413 kJ/m³ (by 31.6%) and 4805 kJ/m³ (by 11.3%).

6. The approximate parameters of RPC concrete mixtures based on alkali-activated slag Portland cements for the manufacture of products using extrusion and 3D printing technologies have been established.

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ВПЛИВ ТЕХНОЛОГІЧНИХ ФАКТОРІВ НА ВЛАСТИВОСТІ РЕАКЦІЙНИХ ПОРОШКОВИХ БЕТОНІВ НА ОСНОВІ ШЛАКОПОРТЛАНДЦЕМЕНТУ, АКТИВОВАНОГО ЛУГАМИ

Андрій РАЗСАМАКІН

Анотація. Розробка реактивного порошкового бетону (РПБ) на основі портландцементів, що містять різну кількість гранульованого доменного шлаку та активовані розчинними силікатами натрію, має глобальне значення з точки зору захисту об'єктів критичної інфраструктури.

У статті встановлено фактори впливу на кінетику набору міцності, власні деформації усадки та на ударну міцність реакційно-порошкових бетонів при використанні метасилікату натрію пентагідрату як лужного активатора у різному агрегатному стані (порошок, розчин), а також розчинних силикатів натрію з силікатним модулем Мс = 2…3. Показано, що зміна співвідношення між шлакопортландцементом і піском від 1:3 до 1:1 та використання метасилікату натрію у вигляді порошку забезпечує отримання піщаного бетону з міцністю на стиск 35.7, 63.8, 87.5, 118.1 та 123.9 МПа через 1, 3, 28, 180 та 360 діб відповідно.

Використання метасилікату натрію у вигляді водного розчину значно прискорює кінетику набору міцності і забезпечує міцність 52.3, 85.0, 108.7, 126.1 та 141.1 МПа через 1, 3, 28, 180 та 360 діб відповідно. Використання розчинного скла з Мс = 2.6 дозволило отримати надшвидкотверднучі високоміцні реакційно-порошкові бетони з міцністю на стиск 19…28, 32.1…45.7, 91.1…129.8 та 102.9…144.6 МПа через 3 години, через 1, 28 і 360 діб відповідно. Введення дрібнодисперсного кальциту зменшило усадку при висиханні РПБ, в 1.2...1.6 рази. Зменшення вмісту портландцементу у шлако-цементній суміші з 45 до 5% мас. при силікатному розчинного скла 2.6...2.7 зумовило незначне зниження ранньої межі міцності на стиск надшвидкотверднучого РПБ, проте забезпечило суттєве підвищення межі міцності на стиск з 112.5 МПа до 132.4 МПа через 28 діб. В'язке руйнування через 28 діб підтверджується кращим коефіцієнтом крихкості 5.3...5.9 та на 10.5…28.7% вищою ударною міцністю зразків на метасилікаті натрію та дисилікаті натрію порівняно з аналогом на основі традиційного цементу. Одержано РПБ зі стабільною довготривалою міцністю, високою ударною в'язкістю та зменшеною усадкою при висиханні. Введення відбілювачів у вигляді $CaCO_3$ та мінеральних пігментів дозволяє отримувати декоративні РПБ. Вказано на можливість отримання виробів екструзією та 3D-друком на основі лужно-активованих РПБ з визначенням основних технологічних параметрів процесу.

Ключові слова: реакційно-порошкові бетони, лужно-активований цемент, міцність, усадка, технологічні фактори.

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