*Leonid Dvorkin**, *Vitalij Marchuk*

National University of Water and Environmental Engineering, Rivne, Ukraine

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Dry mixes on the basis of reactive-powder concrete

ABSTRACT

This article presents the results of experimental studies of mortars based on dry mixes using reactive-powder concrete (RPC). This type of concrete can serve not only as the structural material in the construction of buildings and structures, but also as a semi-finished product for obtaining dry building mixes for various purposes. Redispersed polymer powder as well as fly ash according to the results of the conducted research can be used as additional components for the preparation of various dry building mixes. For development of compositions of dry mixes used the statistical models received by means of mathematical planning of experiments.

Keywords: *reactive-powder concrete, mortar, superplasticizer, composition, properties.*

1. INTRODUCTION

Reactive Powder Concrete (RPC) is the most effective type of fine-grained concrete, which has increased homogeneity, strength and deformability. It was developed in France in the 90s of the 20th century [1]. For such concrete, the typical compressive strength is in the range from 100 to 200 MPa, and can be several times higher than the strength of conventional concrete [2]. As shown by the data of many researchers [3-5], RPC, along with high strength, also has a high crack resistance, which is characterized by the ratio of compressive strength to flexural strength. This ratio for RPC is in the range from 3.5 to 5 [2], while traditional high-strength concrete – 8…10 [1]. The combination of ultra-high strength and high deformability in the reactive-powder concrete is additionally provided due to the dispersed reinforcement with steel or polymer fibers [3-10].

The RPC does not contain a coarse aggregate. Instead, fine powders are used, such as fine quartz sand, ground quartz with particle sizes from 0.045 to 0.6 mm, microsilica, fly ash, ground slag and others. The term "reactive-powder" reflects the fact that all dispersed components in the RPC during curing time undergo chemical transformations.

*Corresponding author: Leonid Dvorkin
Emai: dvorkin.leonid@gmail.com
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The high mechanical characteristics of RPC can be explained by the following features:

1. increasing the homogeneity by eliminating of coarse aggregates;
2. increasing the density by optimizing the grain composition of the mixture of components;
3. increasing the content and improving the properties of the cementitious matrix by adding active mineral additives and by reducing the water-binding ratio with the introduction of superplasticizing additives.

The effectiveness of RPC is confirmed by data on its use in unique structures [8-11]. Due to its increased strength, durability and radiation resistance, RPC can be used as a material for reliable containers with radioactive wastes from nuclear power plants. It is also used for thermal protection of building structures, as it provides better fire and heat resistance than ordinary high-strength concrete.

Dry building mixes (DBM) are becoming increasingly important in construction due to a number of advantages over commercial mortar mixes. In some cases, the operation of large plants for the production of commercial mortar mixtures becomes inefficient due to increased transport costs. The use of DBM helps to increase productivity and quality of work, reduce transportation and storage costs, reduce technological operations [12,13]. Changing of the basic properties of DBM by changing the content of various components creates a wide range of materials needed for the construction of structures and thus allows to use them in all types of work. The production of dry mixtures is possible centrally in factories or directly on construction sites with the use of semi-finished products. Reactive Powder Concrete (RPC) can be used as such a semi-finished product. RBC before mixing with water can be considered as a dry mix containing a binder (Portland cement), a disperse filler (fine sand, ash, etc.) and superplasticizer, as well as additives-modifiers (microsilica, metakaolin and others). These mixes provide high strength, adhesion and durability of concretes and mortars in different operating conditions.

2. MATERIALS AND METHODS OF RESEARCH

Obtaining the necessary compositions of dry building mixes was performed by adding to the basic recipe RPC (Portland cement (PC) – 35%, fly ash (A) – 15%, quartz sand fraction 0.15…0.63 – 50%, polycarboxylate superplasticizer 0.5% by the mass of cement,) additional amount of fly ash (A), as well as redispersed polymer powder (RPP) Neolith P 4400 (vinyl ester of versatic acid). The compressive strength of RPC at the age of 1 day was 36.8MPa, 7 days – 77.0MPa, 28 days – 100.1 MPa.

The average chemical composition of cement and fly ash is given in table.1.

Table 1. Chemical composition of raw materials of RPC

Tabela 1. Hemijski sastav sirovina RPC

Material	The content of oxides, %								
	L.O.I.	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O
Portland cement	-	21.80	5.32	4.11	66.80	0.95	0.63	0.54	0.42
Fly ash	4.91	53.35	22.66	9.21	2.10	2.0	2.32	3.45	

The mineralogical composition of clinker of used Portland cement is follows: C_3S – 57.10%, C_2S – 21.27%, C_3A – 6.87%, C_4AF – 12.19%. Quartz sand had a modulus of fineness M_f – 1.5…2.0, specific surface area of fly ash – 290 m^2/kg.

To study the influence of mixes composition on the basic properties of mortars, algorithmic experiments were performed in accordance with the three-level three-factor plan B_3 [14]. Conditions for planning experiments are given in table. 2.

Table 2. Conditions for planning experiments

Tabela 2. Uslovi za planiranje eksperimenata

Influencing factors		Variation levels			Interval
Natural view	Coded view	–1	0	+1	
RPC content, kg/t	X_1	500	650	800	150
Ash content, kg/t	X_2	0	50	100	50
RPP content, kg/t	X_3	0	10	20	10

Tests of mortars were carried out in accordance with current regulations DSTU B.V.2.7-239:2010 and DSTU B.V.2.7-126:2011 (Ukr. Standards). In the course of research at each point of the plan B_3 mortars based on RPC with constant water consumption of 120 l/t of dry mix were used.

Consumption of sand was found on the condition of the need to bring the total content of DBM components to 1 ton.

3. EXPERIMENTAL RESULTS AND THEIR ANALYSIS

In table. 3 showed the obtained experimental results of the performed studies of mortars based on dry mixtures.

Statistical processing of experimental data (Table 3) allowed to obtain the equations of regression of fluidity, water absorption, compressive and flexural strength, as well as the adhesion of the investigated mortars. General type of equations:

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 \quad (1)$$

where y is the calculated value of the studied parameter;

$x_1…x_3$ are independent variables (factors) that can be varied during experiments;

b_0, $b_1…b_3$, $b_{11}…b_{33}$ are statistical estimates of regression coefficients.

Table 3. Experimental results of investigations of mortars based on RPC
Tabela 3. Eksperimentalni rezultati ispitivanja maltera na bazi RPC

Point of plan B_3	Cone penetration, CP, mm	Water absorption, W,%	Bending strength, MPa, ($f_{m, tf}$) at the age of days			Compressive strength, MPa (f_m), at the age of days			Adhesion, A_d, MPa
			1	7	28	1	7	28	
1	128	0,9	6,29	14,52	18,7	41,4	51,4	73,1	2,49
2	84	1,5	7,09	14,08	16,6	49,8	66,6	82,6	0,73
3	108	2,1	5,49	12,1	16,8	28,8	39,2	59,9	2,19
4	54	2,8	5,89	11,44	14,1	40,4	46,9	70,0	0,59
5	143	1,4	3,49	9,57	13,9	13,5	27,6	40,7	1,79
6	105	3,5	5,89	7	7,4	32,2	33	46,6	0,41
7	135	2,6	3,09	8,8	13,5	11,5	24,3	36,3	1,53
8	87	3,9	5,09	6, 1	6,4	20,8	35	42,8	0,33
9	105	1,6	6,64	13,2	17,3	38,8	52,1	69,7	1,20
10	129	2,7	4,84	8,69	11,1	18,8	28,2	39,9	0,55
11	122	1,8	5,64	11,88	16	28,9	43	60,6	1,10
12	103	3,0	4,84	10,78	14,5	23,1	39,7	52,1	0,90
13	118	1,6	4,49	11,99	16,6	20,1	40,6	53,4	2,10
14	72	2,7	5,89	10,12	12	36,8	42,6	61,4	0,40
15	109	2,0	5,44	11,11	15,2	24,3	41	56,0	1,10
16	110	2,2	5,5	11,55	15,2	25	41,2	57,3	0,95
17	105	2,1	5,3	11,22	15,1	25,3	42	56,9	1,00

Analyzing the coefficients of regression equations of mixtures fluidity (Table 4), the studied factors can be placed according to the magnitude of the impact in the next descending series $X_3 > X_2 > X_1$, there is also a negligible effect of the interaction of these factors. Increasing the content of RPP and ash has a positive effect, and increasing the amount of RPC on the contrary. Analysis of the interactions of the coefficients of the equations clearly shows that with increasing the content of RPC in combination with a decrease in ash consumption is some decrease of the mortars fluidity.

Table 4. Coefficients of regression equations

Tabela 4. Koeficijenti regresionih jednačina

Coeffi-cients	Cone penetration CP, mm	Water absorption, W, %	Bending strength, ($f_{m, tf}$), MPa			Compressive strength, (f_m), MPa			Adhesion, (A_d), MPa
			1 day	7 days	28 days	1 days	7 days	28 days	
b_0	108,7	2,12	5,44	11,4	15,15	25,77	41,7	56	0,98
b_1	-12	-0,53	0,9	2,40	3,12	10,24	11,81	14,9	0,26
b_2	9,5	-0,53	0,4	0,78	0,74	4,12	4,66	4,25	0,1
b_3	23	-0,57	-0,7	0,70	2,30	-6,47	-3,10	-4,1	0,76
b_{11}	7,6	0,02	0,3	-0,4	-0,99	2,44	-1,69	-1,24	-0,08
b_{22}	3,4	0,24	-0,20	-0,03	0,11	-0,36	-0,5	0,31	0,05
b_{33}	-14	-0,03	-0,25	-0,3	-0,84	2,09	-0,25	1,41	0,3
b_{12}	3	-0,11	0,10	0,43	0,37	1,08	2,59	2,20	0,01
b_{13}	1,3	0,26	0,40	-0,37	-1,11	1,00	-2,10	-0,88	0,1
b_{23}	-2,5	-0,09	-0,10	-0,04	-0,15	-0,78	-1,53	0,15	0,04

An increase in the content RPC, RPP and fly ash within the range of their variation approximately equally reduced the water absorption of mortars.

Analysis of the obtained coefficients of the equations for strength indicators (Table 4) shows that the most noticeable effect is the content of RPC and polymer powder. There is also a significant impact of the effects of the interaction of factors. The determining factor for increasing the adhesion of mortars is the presence of RPP.

To analyze the obtained regression equations, two-factor graphical dependences obtained, which illustrate the influence of compositional factors on the properties of mortar mixtures and hardened mortars (Figs. 1...7).

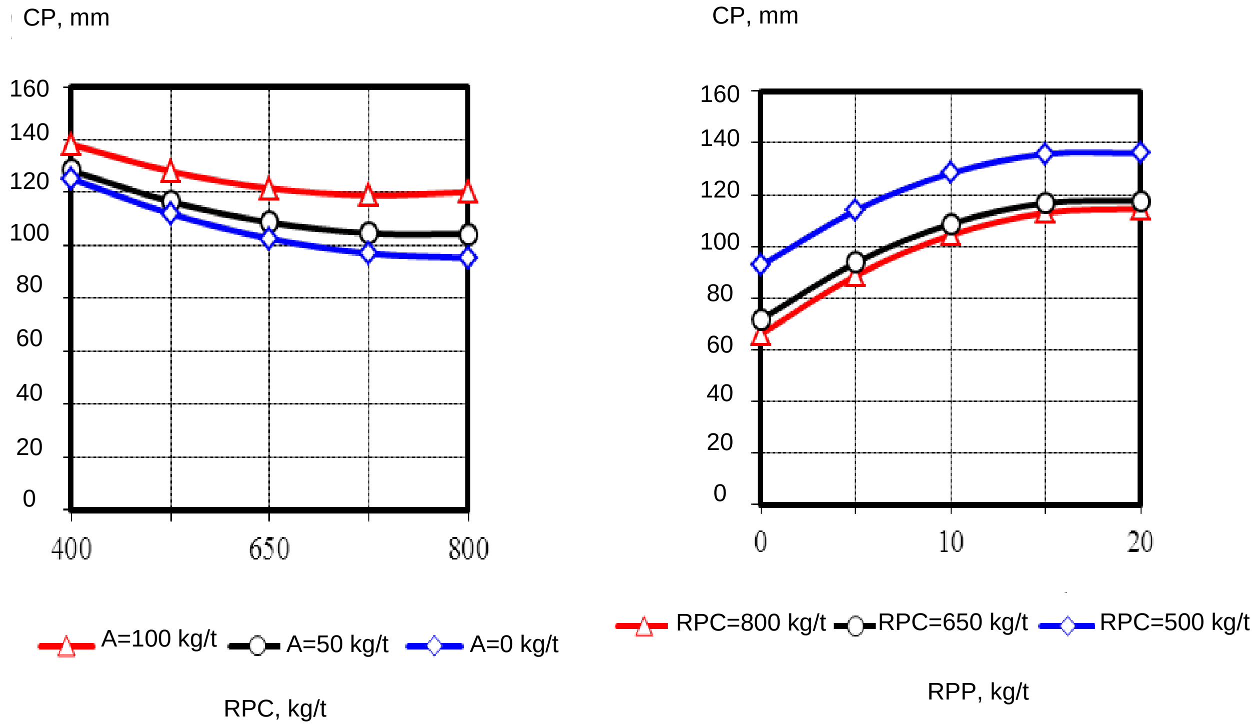

Figure 1. Graphic dependences of fluidity for mortar mixtures based on RPC

Slika 1. Grafičke zavisnosti tečnosti za malterne mešavine na bazi RPC

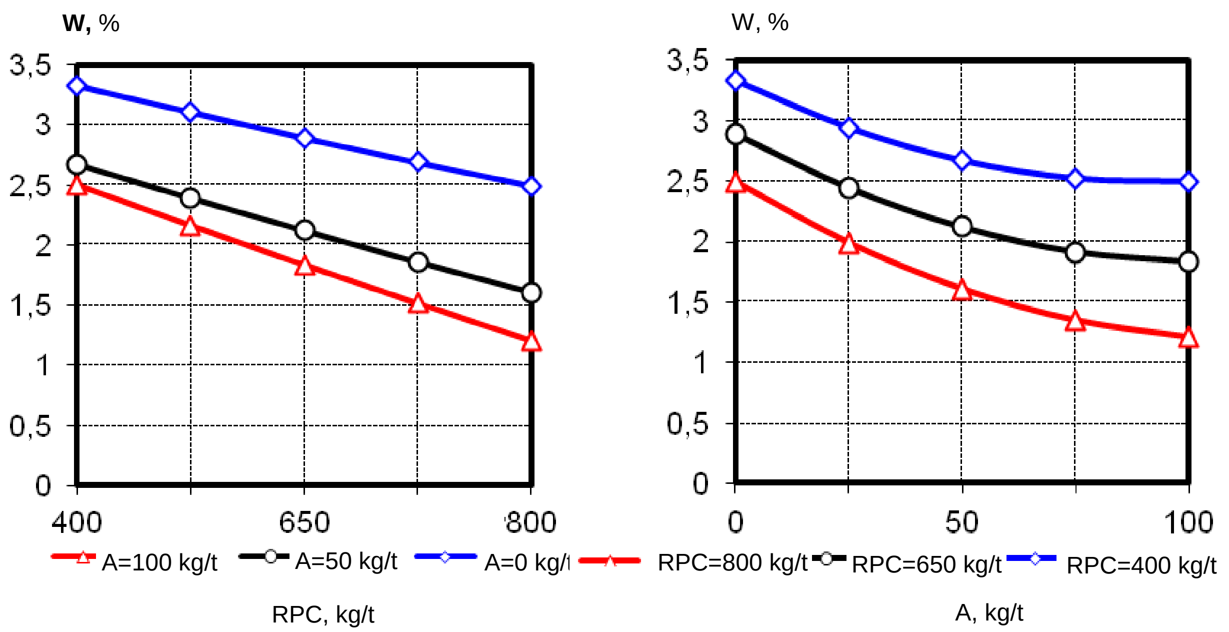

Figure 2. Graphic dependences of water absorption of mortars based on RPC

Slika 2. Grafičke zavisnosti vodoapsorpcije maltera na bazi RPC

Low water content of mortar mixes based on the studied RPC, increased relative density of cement stone, intensive hydration and hardening determine the corresponding features of the pore structure of the mortars. Analysis of the data given in table. 3 and in Fig. 2 shows that, as expected, the increase in the content of RPC and ash in mortar mixes led to a significant reduction in water absorption as a characteristic of open capillary porosity due to the reduction of water content.

Increasing the dosage of RPP to 2% by weight of the mix is accompanied by a decrease in water absorption by 50…60% at the maximum content of RPC (800 kg) and almost 2 times at moderate consumption of RPC (500 kg).

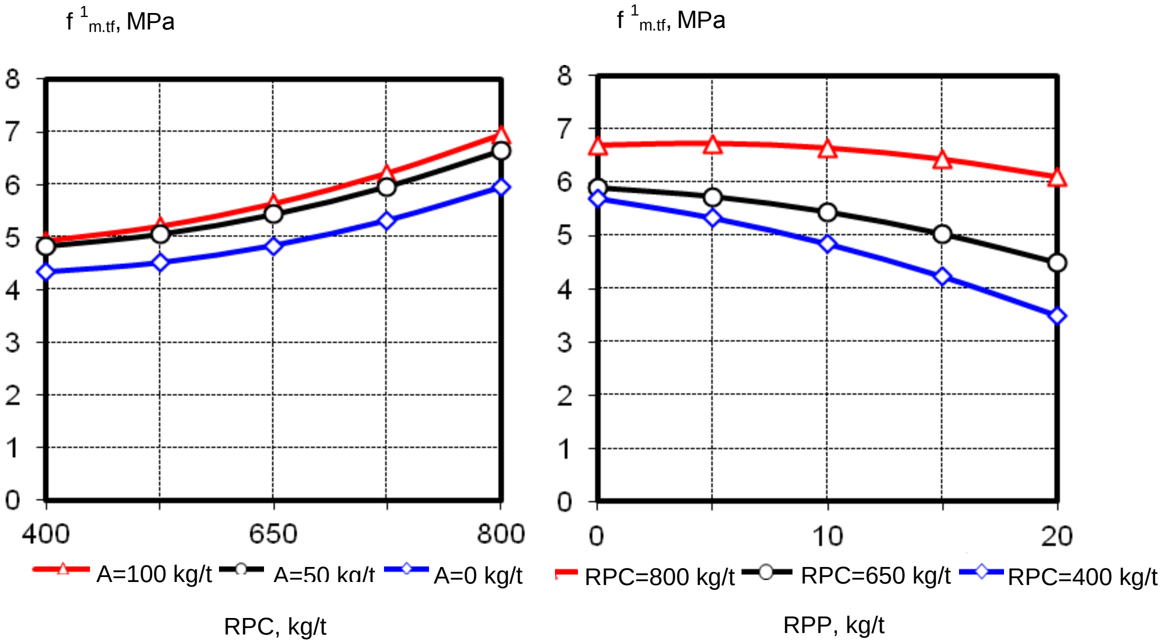

Figure 3. Graphic dependences of flexural strength at 1 day mortars based on RPC

Slika 3. Grafičke zavisnosti čvrstoće na savijanje posle 1 dan maltera na bazi RPC

In the process of film formation in the curing mortar, polymer films are formed that close the micropores and polymer "bridges" that connect the edges of the microcracks of internal defects.

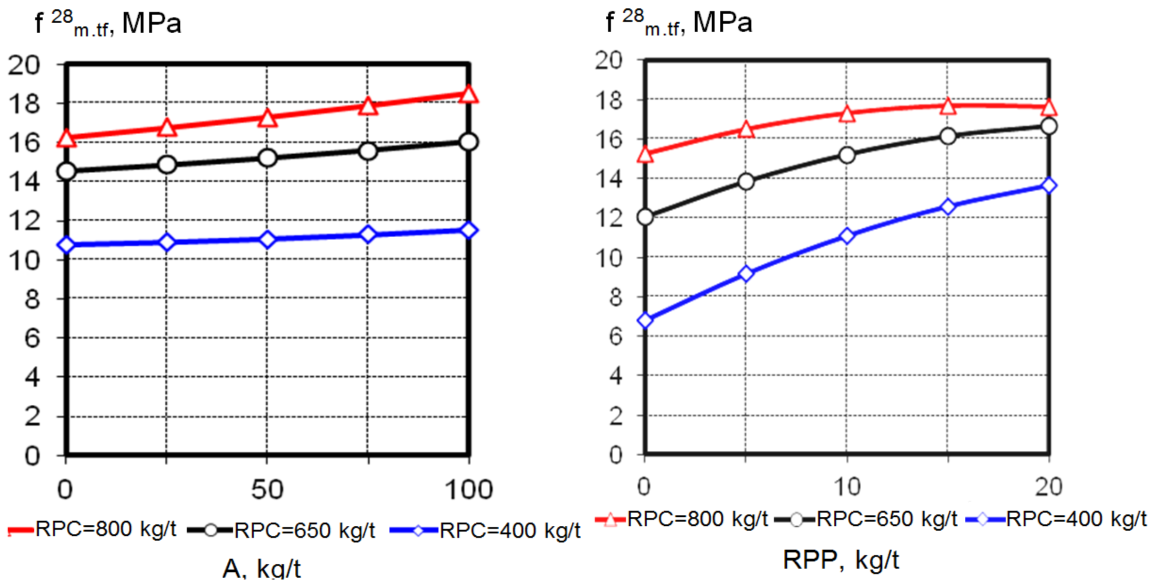

Figure 4. Graphical dependences of flexural strength of mortars based on RPC at 28 days

Slika 4. Grafičke zavisnosti čvrstoće na savijanje maltera na bazi RPC posle 28 dana

There is a certain optimum content of RPC and RPP in the mortars, which preserves the integrity of the cement gel in the structure, the polymer fills the smallest pores and capillaries, and envelops the cement growths and filler particles.

Analyzing the obtained graphical dependences, shown in Fig. 3 and 4 can be concluded that within the variation of factors the strength of mortars in bending is determined by the content of RPC. Increasing the consumption of RPC from 500 to 800 kg/t allows to increase early strength by 40…50%, and in mixes with low RPC content there is an increase in strength by 8...12%. Reducing the ash content within the selected limits may also reduce or not affect strength.

An increase in the content of RPP in the mixture can cause both an increase and some decrease in the strength of the mortars. Influence of RPP on 1-day strength of mortars causes a negative effect, which is leveled at the maximum consumption of RPC and moderate to 1% of the polymer powder. At the age of 7 and 28 days Neolith P 4400 has an extreme effect at the maximum content of RPC.

The increase in flexural strength of the mortars at a RPP content of 1% is observed with a simultaneous increase in the content of fly ash and a decrease in RPC.

Analysis of the obtained graphical dependences (Fig. 5) shows that in the range of variation of the studied factors on the compressive strength of mortars at the age of 1 day, the determining factor is also the consumption of RPC. Increasing the content of RPC from 400 to 800 kg/t allows to increase the strength by 50…70% with an ash consumption of 0…50 kg. The effect of the introduction of fly ash has a less significant effect, increasing its content to 50 kg/t can increase the strength of mortars by 10…15% at moderate content of RPC (400…500 kg/t) and 25…30% at maximum content within variation. This is the formation result of a dense structure due to the initial strength of the contacts, the uniform distribution of grain particles of the binder and aggregate and the activation of crystallization processes.

The introduction of RPP in the amount of 10% leads to a decrease in early strength by 25…30% at the maximum proportion of RPC and 70…100% with increasing RPP content to 20% (fig. 5). This is due to the excess amount of air involved in the composition of the mixture, as well as slowing down the hydration of cement stone in the presence of polymers.

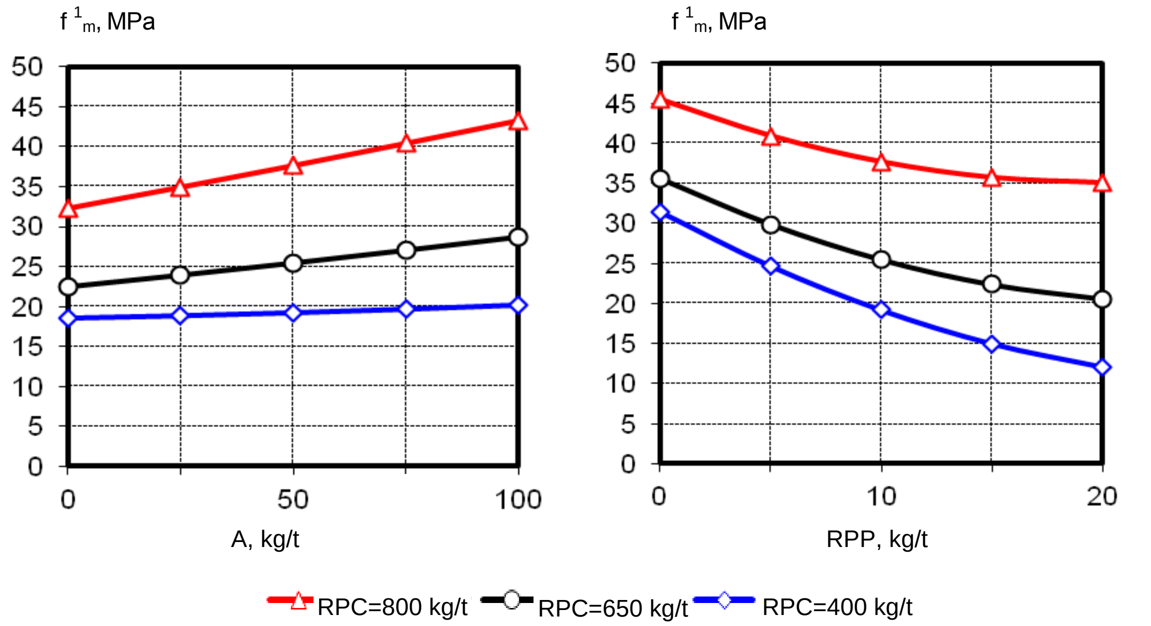

Figure 5. Graphic dependences of compressive strength at 1 day for RPC-based mortars

Slika 5. Grafičke zavisnosti čvrstoće na pritisak nakon 1 dan za maltere na bazi RPC

Analyzing the obtained graphical dependences (Fig. 6), we have that in the studied range of changes in the factors of the composition of dry mixtures, it is possible to obtain mortars with 28-day compressive strength of 36.6…82.6 MPa. At the age of 7 days, the strength of mortars reaches

65…82% of the branded 28-day strength. Strength naturally decreases with changes in the composition of mixtures that lead to an increase in water-cement ratio. In this regard, the impact of RPC and ash consumption is particularly significant.

On the graphs of 28-day strength (fig. 6), the most significant linear effects are shown for factors characterizing of consumption RPC and fly ash. The increase in the strength of mortars with increasing content of reactive powdered concrete is more significant with high ash content. At insufficient content of the RPC in mortar mixtures, an increase in strength is practically not observed. The decrease in strength is inherent in the maximum dosage in the mortar mixture of RPP, which is due to the significant amount of air involved in the composition of the test mix.

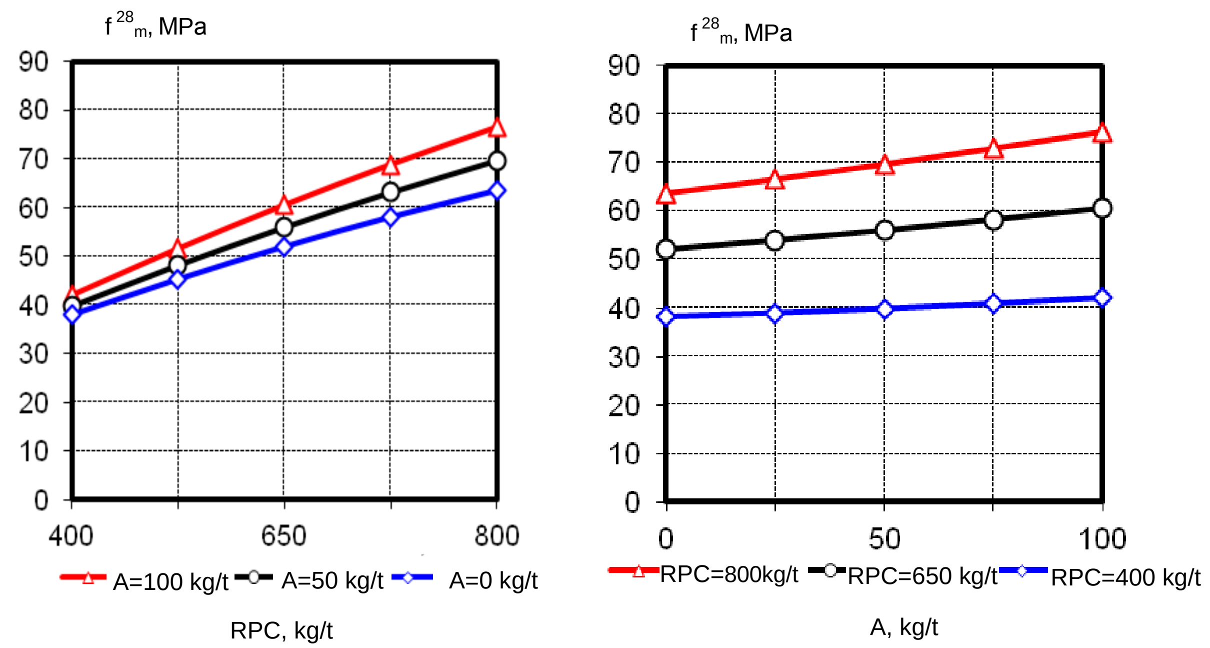

Figure 6. Graphic dependences of compressive strength at 28 days of mortars based on RPC on compositional factors

Slika 6. Grafičke zavisnosti čvrstoće na pritisak posle 28 dana maltera na bazi RPC od kompozicionih faktora

The positive effect of ash and RPC on the strength of mortars can be significantly reduced with suboptimal consumption of polymer powder.

Achieving certain values of strength of mortars is possible at different ratios of factors that characterize the content of the main components. The joint introduction of dispersed components has a positive effect on the strength of the mortar even at constant water content, which can be explained by the creation of better conditions for compaction and interaction between particles in the hardening mortar.

Analysis of the obtained data table. 3 and fig. 7 shows that the use in mortars as the main component of the RPC makes it possible to provide in the studied range of sufficiently high values of adhesive strength (up to 2.5MPa), significantly exceeding the norm. The determining factor is the content of RPP, the introduction of which in the amount of up to 2%, allows to increase the adhesive strength of the mortar in 3…4 times or 0.9…1.6 MPa.

Increasing the amount of fly ash in the mortars to 50 kg is accompanied by an increase in the strength of adhesion to the base by 8…12%, and with a further increase in ash content to 100 kg/t – 25…30%. Such influence of the mentioned technological factors on the adhesion can be explained not only by the influence of the porosity of the contact layer, but also by the degree of wetting of the base by mortar.

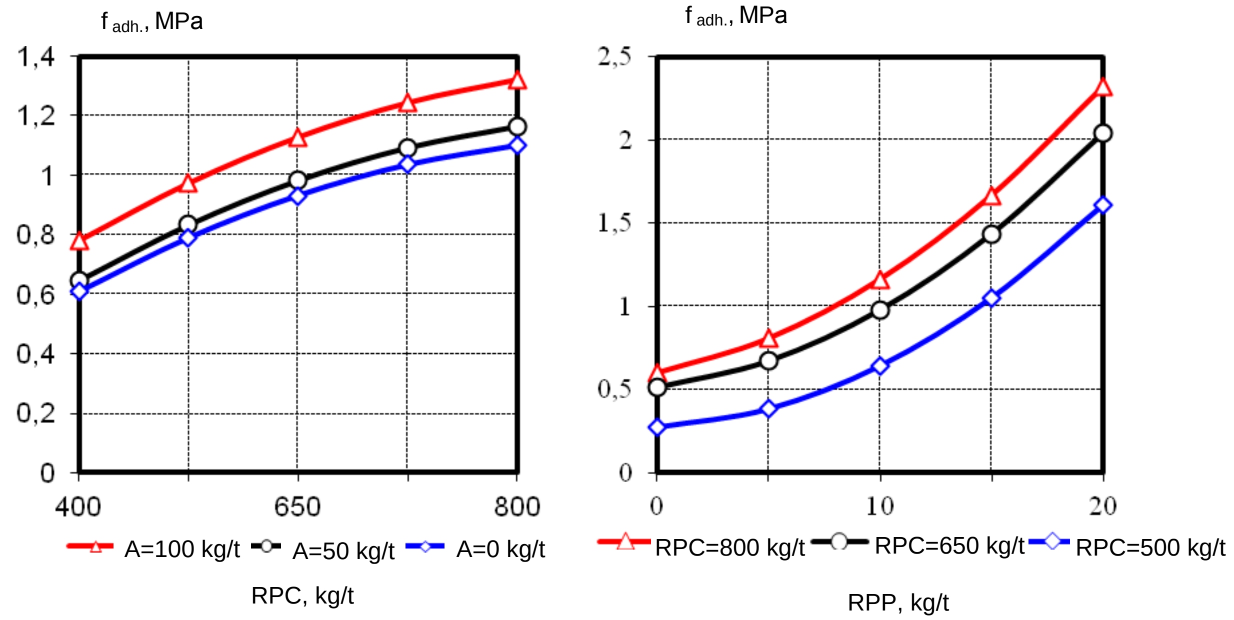

Figure 7. Graphical dependences of adhesive strength of mortars on based on RPB from compositional factors

Slika 7. Grafičke zavisnosti adhezivne čvrstoće maltera na bazi RPB od kompozicionih faktora

Superplasticizer Melflux in reactive-powder concrete has a positive effect on the adhesion of mortars as a result of changes in their surface energy and as a result of changes in the quality characteristics of the contact layer, primarily by increasing its wettability and reducing excess moisture.

On the basis of the conducted researches of use RPC of the offered composition as a semi-finished product when correcting it with the addition of fly ash and redispersed polymer powder it is possible to receive dry building mixes of various functional purpose [14] in particular:

- mixes for repair and renovation of surfaces and structures;
- masonry mixes;
- mixes for fixing materials;
- mixes for the floor coverings;
- mixes for plastering;
- waterproofing mixes for rigid, elastic and waterproofing of thermal insulation systems;
- mixes for the construction of buildings using a 3D printer, etc.

Possible compositions of dry building mixes based on RPC for various purposes and their main characteristics are given in table. 5.

Table 5. Typical compositions of dry construction mixes based on RPC

Tabela 5. Tipični sastavi suvih građevinskih mešavina na bazi RPC

Purpose of mixes	The composition of the dry mixer, kg/t			
	RPC	Ash	RPP	Sand
Masonry	300…500	0…50	–	450…700
Repair	500…700	0…100	10…20	180…490
For arrangement of floor couplers	400…650	50…100	–	250…550
For floor coverings	400…650	50…100	5…15	235…545
For fixing materials	300…500	50…100	10…20	640…380
Plaster	300…500	0…100	0…5	395…700
Waterproofing	400…600	0…100	10…20	280…590
Mixes for 3D printer	500…800	0…100	0…10	90…500

4. CONCLUSIONS

1. Reactive-powder concretes of the recommended composition can be used as a semi-finished product to obtain dry building mixes for various functional purposes.
2. Redispersed polymer powder as well as fly ash can be used as additional components for the preparation of mixes for various purposes.
3. For development of compositions of dry mixes it is expedient to use the statistical models received by means of mathematical planning of experiments.

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IZVOD

SUVE MEŠAVINE NA OSNOVU REAKTIVNOG BETONA U PRAHU

U ovom članku su prikazani rezultati eksperimentalnih ispitivanja maltera na bazi suvih mešavina sa reaktivnim praškastim betonom (RPC). Ova vrsta betona može poslužiti ne samo kao konstrukcijski materijal u izgradnji zgrada i objekata, već i kao poluproizvod za dobijanje suvih građevinskih mešavina za različite namene. Redispergovani polimerni prah kao i elektrofilterski pepeo prema rezultatima sprovedenih istraživanja mogu se koristiti kao dodatne komponente za pripremu različitih suvih građevinskih mešavina. Za izradu kompozicija suvih mešavina korišćeni su statistički modeli dobijeni pomoću matematičkog planiranja eksperimenata.

Ključne reči: *reaktivni praškasti beton, malter, superplastifikator, sastav, svojstva.*

Naučni rad

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