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Development of Multicomponent Binders Using Fine Powders

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***Abstract* –The paper discusses the issues associated with the development of multi-component binders and high-quality concrete on their basis. The basis for the preparation of such binders is the use of finely divided mineral additives of natural and man-made origin. Particular attention is paid to the aggregate, the strength of coarse aggregate should be at least 20% higher than the strength of concrete, and the maximum particle size should not exceed 8–20 mm. To date, considerable experience has been gained in the production of multicomponent binders, and the results of the research carried out in this direction have shown that the raw material potential of the republic allows obtain high-quality concrete of class B 30-40. As if to expand the geography of natural resources regions of the North Caucasus Federal District, it is possible to obtain concrete of higher strength.**

Keywords – high-quality concretes; composite binders; reactive mineral components; volcanic ash; thermoelectric power station (TPS) ash; fractionated aggregate.

I. INTRODUCTION

Concrete is one of the most ancient materials, but its potential and possibilities seem inexhaustible [2, 3, 4, 10], since at all times of its existence and in the future this material will occupy a leading place among a huge variety of construction compositions.

The main active component of concrete is cement. It is known that, by varying finely dispersed mineral additives in its composition, it is possible to obtain modern composite materials whose properties will vary in wide ranges. The systems thus obtained are called multicomponent binders.

It has been established that the mineral components added to the composition of both the binder and the concrete, after preliminary mechanical activation, to a certain degree of dispersion, allow significantly reducing the consumption of Portland cement increase the design class of concrete and produce products with certain properties of lower cost. In addition, there is a positive effect on the degree of hydration of clinker minerals and the formation of an improved concrete microstructure [1, 5, 6–13].

Mineral components used to obtain multi-component binders can be divided into two large groups:

- mineral additives with hydraulic properties (AMD);
- additives - fillers that improve the grain composition and structure of hardened cement stone and concrete.

In accordance with State standards 31108-2003, granulated slag, fuel ashes, including sour or basic fly ash, silica fume, burnt clay, burnt shales, marl, flask, tripolite, limestone powder, quartz sand are used as mineral components - the main components of cement [6–8, 14–18]. Various mineral additives can be used as auxiliary components of cement, which will not significantly increase the water demand of cement, as well as reduce the durability of concrete.

II. METHODS AND MATERIALS

As part of the work carried out in this direction, formulations of multicomponent binders have been developed, which include mineral additives of natural and technology-related origin.

The North Caucasus has large reserves of natural raw materials for carrying out research; the deposits of limestone, dolomite, sandstone, volcanic rocks, and fine quartz sand are practically inexhaustible.

Chemical analysis and the basic properties of the mineral components used in the studies are shown in Tables 1 and 2.

TABLE I. CHEMICAL COMPOSITION OF MINERAL COMPONENTS, %

Oxide composition	Ash (TPS)	Volcanic ash	Limestone powder	Quartz powder
MgO	2.49	0.20	0.72	6.32
Al_2O_3	23.89	13.57	1.55	14.99
SiO_2	42.88	73.67	5.05	73.83
K_2O	0.48	6.00	0.6	1.83
CaO	4.6	1.79	90.1	0.6
Fe_2O_3	7.95	1.52	1.4	0.97
TiO_2	0.11	2.85	-	1.32
SO_3	0.66	-	0.49	0.14
p.p.p.	16.9	0.40	-	-

TABLE II. PROPERTIES OF FINELY GROUND MINERAL COMPONENTS

№	Name of mineral component	True specific gravity, kg/m^3
1	Limestone powder	2620
2	Volcanic ash	2400
3	Ash of Grozny TPS	2000
4	Quartz powder	2600

III. Results

The study of grains of reactive finely ground mineral components of various genesis was carried out on a Quanta 3D 200 i scanning electron microscope with an integrated Genesis Apex 2 EDS microanalysis system from EDAX. It was found that the surface of the ash microspheres does not contain defects in the form of growths or cracks, there are irregularities of various shapes and sizes, and the individual microspheres have a closed porosity of the membranes, and the content of amorphous silica particles has been established (Figure 1a).

Volcanic ashes consist mainly of crystals of plagioclase, pyroxene, magnetite, hornblende, volcanic glass of different composition and rock fragments (Fig.1b). The surface of the limestone dust grains is represented by calcite, aragonite and dolomite, irregularities of various shapes and sizes were found, the closed porosity of the membranes of individual particles was established (Fig.1c). Particles of quartz powder grains consist mainly of quartz, feldspar and a small amount of mica, micron particles are dominated, the fragmentation of particles is prevail, which indicates increased activity (Fig. 1d).

To identify the optimal degree of saturation of the «Portland cement - mineral powder» system (PC: MP), the normal thickness of the cement paste was determined and the balancing specimens of size 40X40X160 mm were prepared in the ratio of PC: MP = 70: 30 and PC: MP = 60: 40, Table 3 summarizes the results of the study.

To obtain multicomponent binders, the prerequisite was the preparation of fine powders, for which the additives under study were ground in a VM-20 laboratory vibratory ball mill for 30 and 40 minutes. The specific surface of the obtained powders was determined on the device PSKH-12, by the method of air permeability, which is based on the resistance of the layer of cement to the air passing through it. The test results are shown in Table 3. Figure 2 shows the dependence of the specific surface of mineral additives on the time of grinding. Analyzing the results of activation, it can be noted that the highest grind ability of ash and limestone, the specific surface of these powders is 876-890 m^2/kg. The minimum results were obtained for quartz sand, which is probably explained by the fact that it contains almost 74% of silica, which is a fairly solid mineral.

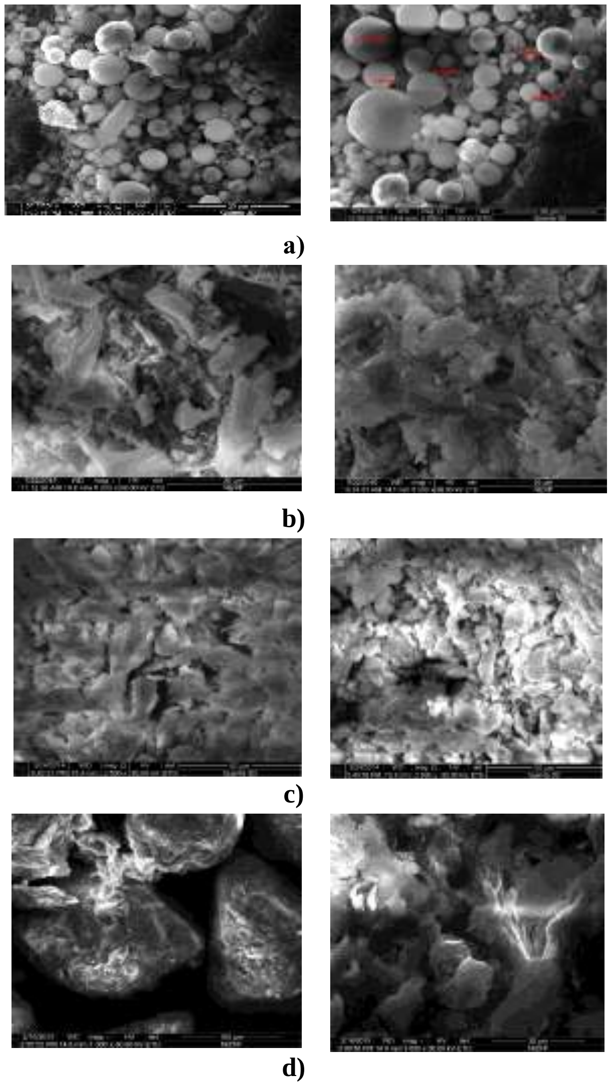

Fig. 1. Micrographs: a) ash microspheres of TPS, Grozny; b) volcanic ash particles; c) limestone powder particles; d) sand grains of Vedensky field

The results of the studies showed that the most rational are the compositions of binders using mineral powders of volcanic ash and quartz powder with a ratio of 70:30%, with a specific surface of 876 m^2/kg and 650 m^2/kg, respectively, with a typical increase in the activity of the binder and a slight increase in normal thickness, and there is also a saving of up to 30% Portland cement.

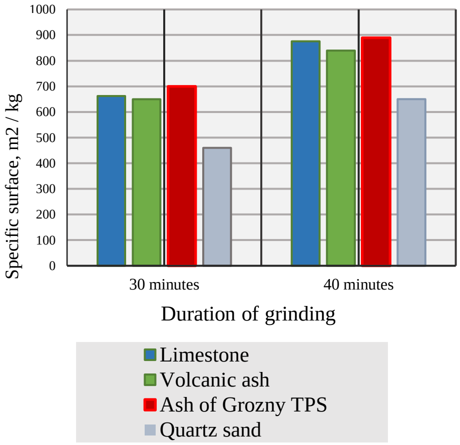

Fig. 2. Specific surface of mineral components

Next, the molding mixtures were prepared, which included the developed binder formulations (MCB-70) on the additives we studied. As noted above, to obtain high-quality concretes, crushed stone from granite-diabase rocks of a fraction of 5-10 and 10-20 mm was used, which was purchased for testing from RSO-Alania.

TABLE III. PROPERTIES OF MULTICOMPONENT BINDERS (MCB)

№	MC	PC / MP	Normal density, %	Setting time , h-min		Activity of MC
				beginning	end	
1	LP	70/30	25.5	2-05	3-00	35.8
2		60/40	26.8	2-15	3-20	30.4
3	QP	70/30	24.6	1-30	2-10	41.8
4		60/40	27.0	1-55	2-50	39.7
5	A	70/30	26.4	2-10	3-15	34.1
6		60/40	28.1	2-25	3-35	28.2
7	VA	70/30	25.2	1-35	2-15	42.6
8		60/40	26.5	2-05	3-00	40.3
9	-	100	25.0	2-20	3-40	48.0

[a] Note: LP – Limestone powder; QP – Quartz powder; A – Ash of Grozny TPS; VA – Volcanic ash; MP – Mineral powder

Fine aggregate was obtained by fractionation of quartz-fieldspath sand Mcr = 2.8 - State standard 8736 of the Alagirsky field with fine quartz sand Mcr = 1.7 of the Chervlensky field - State standard 8736, in the ratio of 75:25%, which was adopted as a result of experimental studies. The basic properties of the aggregates are shown in Table 4–5.

From the studied components, a concrete mixture was obtained with a draft of a cone from 5 to 10 cm, which corresponds to the grade of mobility P2. Of the concrete mixture of each composition, 9 cubic samples with an edge of 10 cm were molded, of which 6 samples were heat treated in a steam chamber at 2 + 3 + 7 + 2 hours at an isothermal holding temperature of 80°C, the rest were naturally hardened for 28 days. Table 6 shows the experimental compositions and properties of the studied concretes.

TABLE IV. BASIC PROPERTIES OF THE FINE AGGREGATE

Name of the indicator	Manufacturers- mining plant	
	Chervlensky	«Progress» LLC RSO-Alania
Sieve residue № 063, %	3,0	65,0
Content of dust and clay particles ,% by weight	2,0	2,1
Gradation factor , M_{cr}	1,7	3,12
True particle density , kg/m^3	2740	2770
Packed density , kg/m^3	1405	1620
Porosity , % ppbv	48,9	42,0
Clay content in globs , % by weight	absent	absent
Reactive content of (amorphous)silica SiO_2, mmol / l	123	20
The content of organic impurities (color of solution)	Solution is lighter than sample	Solution is lighter than sample
Group by grain	extra fine	extra coarseness

TABLE V. BASIC PROPERTIES OF THE COARSE AGGREGATE

Break- stone of the Alagirsky field of fraction, 5-20 mm						
Grain composition of break-stone	Sieve size , mm	12,5	10	7,5	5	<5
	Partial residuals, %	0,0	9,2	38,6	42,5	9,3
	Complete residuals, %	0,0	9,2	47,8	90,3	99,6
Strength test of break- stone		M1200				
Content of dust and clay particles, %		0,8				
True particle density , kg/m^3		2700				
Packed density , kg/m^3		1450				
Content of the crushed grains, %		85,2				
Determination of the content of grains of lamellar (flap) and needle-shaped forms, %		12,2				
Porosity , % ppbv		44,9				

Analysis of the test results showed that the strength characteristics of concrete vary both depending on the type of finely ground mineral filler used and on the binder consumption. It is established that the strength of concrete after isothermal holding temperature is 12% higher than the indicators of the strength of concrete 28 daily natural hardening.

TABLE VI. COMPOSITIONS OF RESEARCHED CONCRETE

№ composition	MP	Consumption of materials, kg/m^2				Average density, kg/m^3	Compressive strength, MPa	
		MCB-70	B	F	B		After IHT	28 days
1	LP	450	1100	680	220	2430	43,3	38,4
2	QP	450	1100	680	210	2410	50,2	45,9
3	VA	450	1100	680	215	2415	52,1	46,5
4	A	450	1100	680	230	2420	37,7	35,9
5	PC	450	1100	680	200	2420	51,5	48,6

b. **Примечание**: PC– portland cement ; B – Break-stone of the Alagirsky field of fraction,5-20 mm; F– Fractionated fine aggregate based on the sands of the Alagirsky and Chervlensky fields; LP – Limestone powder ; QP – Quartz powder; A – Ash of Grozny TPS; VA – Volcanic ash; MP – Mineral powder

Consequently, the developed concrete formulations can be used in monolithic construction. The use of MCB-70 with volcanic ash showed the best results in compressive strength of concrete in comparison with other additives and is slightly inferior to similar indicators of control samples [2, 4 , 19-22].

The study of performance characteristics, such as water resistance, frost resistance and water resistance, showed that the indicators of these properties depend on the composition of the MCB-70 and its activity, as well as the type and value of the porosity of the material (Table 7, Figure 3).

TABLE VII. OPERATIONAL PROPERTIES OF CONCRETE ON MCB-70

Indicators	Mineral powder			
	LP	VA	A	QP
MCB-70 activity, MP	35,8	42,6	34,1	41,8
Compressive Strength , MP	38,4	46,5	35,9	45,9
Flexural Strength, MP	4,1	4,9	3,8	4,4
Porosity, %	9,7	7,6	12,4	6,9
Frost resistance, cycle	F300	F350	F200	F350
Withstand pressure, MP	1,4	1,8	1,2	1,8
Water absorption , %	4,2	3,5	5,2	3,6
Water resistance , K_p	0,79	0,89	0,63	0,90

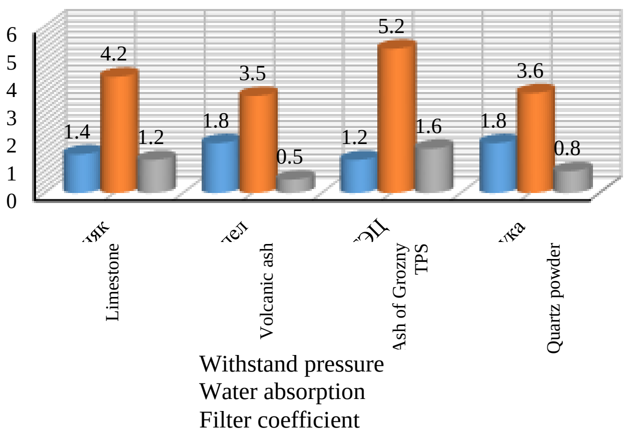

Fig. 3. The dependence of withstand water pressure of the water absorption and filter coefficient

IV. CONCLUSION

Thus, the results of the studies proved the effectiveness of the use of multicomponent binders based on mineral powders of natural and technology-related origin. These developments will allow to obtain high-quality concretes of strength class B30-40, including for high-rise monolithic construction. The proposed concrete formulations allow you make optimal technical and economic decisions, providing the required operational reliability and durability of concrete and reinforced concrete products and structures.

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