

Formation of an optimal cement matrix for vibropress products

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Abstract. Modern approaches to the formation of new generation concretes make it possible to replace part of the fine aggregate with finely ground mineral powders, which are by-products of metallurgical and chemical industries, the construction industry, as well as various substandard quartz sands. In the studies carried out, metallurgical slags (MS), broken glass (BG), dust from gas cleaning of metallurgical production (DGCMP), and ground quartz sand (GQS) were used. The aim of the study is to obtain an optimal flow rate of a hydraulic binder by forming an optimal cement matrix. The dosage of finely ground powders varied in the range of 20-49 % of the portland cement consumption. It has been established that the most acceptable finely ground mineral powders in compositions for the production of vibropress products are: quartz ground sand, metallurgical granulated slag of blast furnace production, gas cleaning dust and ground glass. Powders obtained on the basis of glass scrap can be considered as an additional raw material base in the production of materials for road-building purposes. Operational properties such as water absorption and the rate of concrete curing indicate their prospects. However, the economic costs of collecting, sorting glass, obtaining a powder with a specific surface area of 3000 cm²/g are not reasonable at this point in time.

1 Introduction

Modern production of concrete based on Portland cement is not complete without the widespread use of fine powders, including fine powders. This trend has been seen since the late 60s of the twentieth century. These powders were considered as fillers with an optimal consumption of 5-20% of the mass of Portland cement [1, 2, 3, 4]. The raw materials were: ash from coal combustion, granulated slag, dehydrated clay, crushed expanded clay and micro silica. They contain aluminosilicates and silicon-containing materials in their composition. The considered powders contribute to the formation of an additional pozzolanic reaction (cementing ability) during hardening of the binder, as well as to obtain optimal packing of the composite material with an increase in its density [2, 5, 6]. At the same time, it has not been established with high reliability how to control the properties of composite materials in a targeted manner by changing the filling of the cement matrix and reducing the proportion of Portland cement in the system [1, 7]. In open sources, it was

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practically not analyzed how the fineness of grinding of powders and the ratio of various oxides affect the kinetics of the strength gain of concrete and the ability to form internal defects in the form of cracks. The conducted research is aimed at obtaining highly efficient vibropress concretes with a minimum consumption of Portland cement and a maximum filling of the system with finely ground powders to ensure a good and smooth surface, as well as sufficient physical and mechanical characteristics. Fillers with pozzolanic reactivity will significantly change the physical and mechanical properties of concrete. Vibro-compressed concrete with fillers based on mineral powders will provide both economic and environmental effects for the region and business.

2 Materials and research methods

2.1 Materials

The following materials were used for the study: Portland cement PTC M500 D0 (CEM I 42.5H) - "Asia Cement" - the city of Nikolsk; sand of the Chaadaevsky quarry with a fineness module of $M_{cr} = 1,4-1,6$; crushed quartz sand of the Aleksandrovsky quarry (GQS) with a specific surface area $S_{sp} = 4500 \text{ cm}^2/\text{g}$; ground glass breakage of container glass (BG), powder specific surface $S_{sp} = 2600-3000 \text{ cm}^2/\text{g}$; ground granulated slag of the Novolipetsk Metallurgical Plant (MS) with a specific surface area $S_{sp} = 3000 \text{ cm}^2/\text{g}$, true density $2530 \text{ kg}/\text{m}^3$; gas cleaning dust of the Tula Metallurgical Combine (DGCMP) with $S_{sp} = 4100 \text{ cm}^2/\text{g}$; granite crushed stone, fraction 2-4 mm and 5-10 mm (Karelian granite); hyperplasticizer - Hedital GP-9 γ (dry residue (DR) –19 g/100 ml); drinking water.

2.2 Research methodology

The methodological feature of the research is the production of high-strength vibropress products with a minimum consumption of Portland cement. The experimental technique is described in detail in the article [5]. The physical and mechanical properties of concretes were determined by cubes with a size of $100 \times 100 \times 100 \text{ mm}$, tested for compression at the age of 7, 28, 90 and 360 days of hardening under normal conditions at a humidity of 90 % and a temperature of $T = 20 \pm 5 \text{ }^\circ\text{C}$. Cubes were molded on a vibropress with a weight of 120 kg for 2 samples, molded simultaneously on a laboratory vibrating platform. Water absorption was determined by immersing concrete samples in water at the age of 28 days of hardening under normal conditions and holding for 24 hours according to the generally accepted technique [8, 9]. Ground powders were obtained using a three-stage preparation technology. At the first stage, the materials were dried to constant weight in an oven at a temperature of $T = 105 \text{ }^\circ\text{C}$, and cooled in a desiccator to ambient temperature. The second stage is crushing in a jaw crusher to a fraction of 0-5 mm. At the third stage, the resulting material was ground in a ball mill to a specific surface area set in the experiment, which was controlled by a PSKh-10AK device.

3 Discussion, results

The table 1 shows the results of the optimized compositions of vibropress concretes and their experimental compression tests.

Table 1. Physical and mechanical properties of vibropress concrete for the production of paving slabs

Ingredients	Consumption per 1m ³ , kg									
	Squad number									
	1	2	3	4	5	6	7	8	9	10
CEM I 42.5H	277	362	235	328	240	270	280	219	215	458
Natural sand	-	-	-	-	-	-	-	-	-	1100
Broken glass (BG)	181	96	-	-	-	-	70	-	-	-
Ground quartz sand (GQS)	-	-	-	-	-	-	-	201	198	-
Metallur-gical slags (MS)	-	-	223	130	-	-	70	-	-	-
Dust from gas cleaning of metallur-gical production (DGCMP)	-	-	-	-	218	188	-	-	-	-
Sand fr. 0,16 mm	554	543	625	615	576	528	-	500	610	-
Sand fr. 0,63-2,5 mm	898	957	800	816	870	928	750	684	638	-
Crushed stone 2,5-5 mm	454	261	350	408	348	353	1140	649	546	750
Hedital GP-9γ -0,75 %	7,0	10	7,5	7,7	6,5	6,0	7,0	7,3	7,25	10,0
Water	73	78	90	92	78,3	86	90	89	90	130
Water-cement ratio	0,26	0,22	0,38	0,28	0,33	0,32	0,32	0,41	0,42	0,28
Forming density, kg/m ³	2437	2297	2323	2389	2330	2353	2400	2342	2297	2438
Density for 7 days, kg/m ³	2322	2196	2240	2276	2250	2241	2349	2219	2222	2331
Density for 7 days, MPa	16,63	22,11	23,24	19,54	24,16	24,13	42,8	34,58	29,63	35,18
Density for 28 days, kg/m ³	2258	2074	2140	2157	2135	2116	2245	2226	2219	2211
Density for 28 days, MPa	17,56	22,12	26,25	20,00	27,66	26,62	47,09	49,67	44,89	41,18
Density for 90 days, kg/m ³	2114	2045	2070	2078	2046	2075	2200	2211	2210	2210
Density for 90 days, MPa	38,67	33,12	46,29	43,80	34,67	32,19	51,66	55,39	46,76	43,38
Density for 360 days, kg/m ³	2135	2079	2108	2112	2123	2130	2265	2217	2205	2215
Density for 360 days, MPa	40,00	35,83	49,95	45,03	36,41	34,86	53,07	56,51	48,30	45,55
Vodopo-ironing at the age of 28 days, %	3,2	3,6	4,56	4,80	4,79	4,9	3,8	3,34	3,54	5,9
Type of filling body matrix	BG		MS		DGCMP		BG+MS	GQS		Con- trol

From the results obtained on the optimization of the compositions of the consumption of materials per 1 m³, it can be seen that approximately in all compositions the optimum

moisture content of the mixture was achieved, which is confirmed by good molding and approximately the same density of the samples.

To achieve the maximum density of concrete samples and to be able to remove the formwork after molding, the water-cement ratio varies from 0,22 to 0,42, which indicates the various properties of fillers - finely ground powders. At the same time, the molding density of the concrete mixture varied in the range of 2297-2438 kg/m³. Samples of concrete cubes are formed with a perfectly flat surface, sharp edges and no smudges. After 7 days of hardening, the strength characteristics of concretes with finely ground structure modifiers significantly differed from those of the control composition molded on standard sand and gravel. Positioning in a comparison row from the smallest to the largest of the results obtained allows us to obtain the following dependence: BG < MS < DGCMP < GQS < Control < (BG + MS). The excess of strength of samples with a complex filler of ground granulated slag and ground breaking of container glass relative to the control composition is 122 %, and relative to samples with filling with ground breaking of container glass – 214 %. Moreover, the consumption of Portland cement in the composition of № 7 is reduced by 39 % (compared with the control № 10).

At the age of 90 days, the dependence of the strength of the samples on the type of filler changes: DGCMP < BG < Control < MS < GQS < (BG + MS). Vibroconcrete compositions № 3, 4; 8, 9 and 7 exceed the strength of the control samples by 2-22 %. Samples of compositions № 1, 2 and 5, 6 have lower compressive strength values by 18-24 % (compared to control № 10).

At the age of 360 days, a series of dependences of the compressive strength on the type of filler is as follows: DGCMP < BG < Control < MS < GQS < (BG + MS), that is, the dependence that was achieved at the age of 90 days is confirmed.

Interesting data were recorded on the water absorption of samples at the age of 28 days in a normal hardening chamber. The comparative series is presented in the following sequence: (BG = GQS) < BG + MS < MS < DGCMP < Control. Samples of concrete filled with ground glass have the lowest water absorption value of the entire series. Thus, the use of this type of filler is promising, which will allow for further research to select the optimal filling of the system.

4 Conclusions

1. A positive effect of the dosage of five types of ground fillers of a cement matrix on the properties of vibropress concretes has been revealed. The explication period of the experiment is 360 days. Micro fillers were used as a complex in an amount of 21-49 % to replace Portland cement by weight. The control mixture without finely ground filler powders was compared in terms of compressive strength with five mixtures containing ground granulated slag, ground glass breakage of container glass, ground quartz sand, and gas cleaning dust.
2. The importance of long term testing has been proven. Significant changes in compressive strength occurred in the period from 28 days to 90 days, and later these patterns did not change until the end of the explication period [10, 11].
3. The most optimal modifier of the cement matrix is ground quartz sand with a specific surface area $S_{sp} = 4000-5000 \text{ cm}^2/\text{g}$.
4. The lowest rates of strength gain are possessed by vibropress concretes with the addition of ground broken container glass, however, the water absorption of these concretes is 3,4 % on average, which is lower than all other investigated compositions.
5. The use of ground mineral powders can reduce the consumption of Portland cement by 22-49 % relative to the control composition, which ensures a reduction in the cost of production, improves the environmental situation in the region due to the disposal of

waste from various industries, reduces carbon dioxide emissions into the atmosphere by reducing the production of Portland cement at specialized enterprises.

6. The use of finely dispersed ground mineral powders together with hyperplasticizers in cement compositions and concretes opens up broad prospects for obtaining composite materials with high strength performance properties at a rational consumption of the binder.

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