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A MODEL OF INTERACTION OF TRAVELERS, PARKING AGENCY AND AUTHORITIES FOR OPTIMIZATION FREE AND PAID PARKING

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NONFERROUS WASTE AERATED CONCRETE

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*This article presents studies of the technological process for producing curing monolithic aerated concrete from industrial slag sands. The purpose of this work is to develop and optimize the composition of lightweight concrete using gypsum building plaster as a binder. For the construction of low-rise industrial buildings, it is proposed to use industrial slag components and waste from the Norilsk industrial district. To form a cellular structure of concrete, it was chosen the chemical method of porosity, which involves the implementation of a gas evolution reaction when aluminum powder interacts with calcium hydroxide. During the tests, Portland cement M400 of the Topkinsk cement plant was used, sand with a specific surface area of 4.62; 7.3; 16.48 and 28.85 m²/kg. The study of the parameters characterizing the blowout and structure formation of aerated concrete mixture was carried out in collapsible metal shapes with a base of 0.10*0.10 m, filled to 1/3 of the height. Temperature profiles were recorded by controlling 10 thermocouples for 1-2 minutes using a КСП potentiometer. It was concluded that expanded clay aggregate and sawdust for gypsum-lightweight concrete are active and contribute to its hardening.*

Key words: wall materials, blowout, porous concrete, student t-test

INTRODUCTION

The total cost, architectural and planning capabilities and design solutions of industrial buildings are primarily determined by the type and cost of wall materials. The traditional and most common material for the installation of walls and floors is lightweight aggregate concrete (expanded clay gravel). However, its absence in rural areas of many regions of Russia, the high cost and transportation costs necessitate the use of other types of feedstock – ashes, slags, sludge wastes, and the development of the technological process for the preparation of various mixtures using them.

For the construction of low-rise industrial buildings in a remote area, it was proposed to use industrial slag components and waste from the Norilsk industrial district [1]. This paper provides studies of the technological process for producing curing monolithic aerated concrete from industrial slag sands. In the total amount of slag waste received, the share of lightweight is 75%. This weight suggests the need to develop technology for porous monolithic concrete from very fine-grained industrial sand, the use of which in low-rise construction will expand the mineral raw material base and reduce the cost of the building.

For the formation of a cellular structure of concrete, it was chosen the chemical method of porosity, which involves the implementation of a gas evolution reaction by the interaction of aluminum powder with calcium hydroxide [2]. The installation of walls of monolithic autoclaved cellular concrete using industrial sands of natural grading is a new direction in low-rise construction. The issues related to the influence of the state of components and the composition of the mixture on the blowout and hardening of aerated concrete are insufficiently studied.

To obtain an analytical model with respect to aerated concrete, it is necessary to obtain experimental data characterizing the process of aerated concrete blowout in formwork at curing in the spring-summer period of construction. According to the available theoretical prerequisites [3-7] and the data obtained by preliminary studies, the following factors were selected as technological factors determining the quality of aerated concrete: temperature of gauged water and mixture, sand fineness, content of aluminum powder.

MATERIALS AND METHODS

During the tests, Portland cement M400 of the Topkinsk cement plant was used, as well as sand with a specific surface of 4.62; 7.3; 16.48 and 28.85 m²/kg. The study of the parameters characterizing the blowout and structure formation of aerated concrete mixture was carried out in collapsible metal shapes with a base of 0.10*0.10 m, filled to 1/3 of the height.

In these shapes, a vertically located survey rake of chromel-kopel type thermocouples were rigidly fixed. Temperature profiles were recorded by scanning of 10 thermocouples for 1-2 minutes using a КСП potentiometer. Estimated uncertainty in temperature field measurements was carried out in accordance with [8]. Moreover, the measurement uncertainty is 2.5-3.0%. The test ended in 2.5-3.0 hours, i.e. after stabilization of the volume of the blown-out aerated concrete mixture.

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During the test, the initial water temperature T_w and the component composition were varied. As the main option, a sand composition with S_{sp} = 7.3 m²/kg was used. Component consumption per 1 m³ of concrete: sand – 469.8 kg, Portland cement M400 – 411.1 kg, water – 458 l, lime – 35.2 kg, aluminum powder – 8.2 kg. The mixture was stirred for 3-5 minutes, and then poured into the shape (Table 1).

Table 1: Characteristics of slag sand

Sieve	grain area, mm	volume, mm	weight, g	specific surface area, cm²/g	m²/kg
0.31	0.3	0.01	0.00004	73.02	7.30
0.14	0.06	0.001	0.000003	164.83	16.48
0.08	0.02	0.0002	0.0000006	288.46	28.84
0.5	0.7	0.06	0.0001	46.15	4.61

When optimizing the water-need of the aerated concrete mixture, the maximum swelling of the mixture is taken as a basis while ensuring uniformity. When using sand of a larger fineness (S_{sp} = 7.3 m² kg), water-need decreased by 3%, and a smaller fineness (S_{sp} = 16.48 m²/kg) increased by 2%, due to a change in the total surface of sand grains and the amount of adsorbed water. With the introduction of lime, the water-need of the mixture increased. Increasing the content of aluminum powder in excess of 0.6 kg helps to reduce water-need. It should be noted that the optimal spreadability of the aerated concrete mixture substantially depends on the sand fineness and is in the range of 16-19 cm. In this case, the coefficient of swelling varies insignificantly and is in the range of 1.1-2.58. With a recommended casing thickness of 30-32 cm, the layer lift after the mixture has hardened is 45-50 °C. Determination of the average density, spreadability, coefficient of swelling and compressive strength of aerated concrete mixture was carried out in accordance with GOST 12730.1-78, GOST 10180-89, and quality assessment according to GOST 25485-89 [9-11].

The temperature of the aerated concrete mixture varied from 20 to 40 °C and was regulated by the introduction of hot water. To ensure the temperature of the mixture 40 °C, water was used, heated to 80 °C, and 30 °C to 50 °C, respectively. It was established that the largest value of the swelling parameter is provided in the temperature range of 30-40 °C. At 20 °C, the coefficient of swelling is reduced by 10-20%.

RESULTS AND DISCUSSION

The main technological factors determining the density of aerated concrete are W/N (the consumption of pore agents and the sand fineness). To determine the coefficient of swelling and density of aerated concrete, 30 samples were prepared. All samples were observed within 2-3 hours from the moment the mixture was laid in the shape. At the age of three days, the samples were dismantled, weighed and measured (to determine the density before drying). After that, all samples were dried at a temperature of 90-110 °C in oven with water heating and weighed again (to determine the density after drying). In addition, each mixture was subjected to a flow test, the diameter of the part being measured before and after laying at the installation. The results of the work performed are presented in Table 2.

In the course of the work, it was noted that samples with a high-water content (W/N = 0.7) swell well, but also sag strongly, after hardening they are very light and highly porous, large pores are possibly interconnecting. The density of such samples ranges from 586.96-527.17 kg/m³ depending on the size of the sand fineness. Samples prepared from the finest sand (specific surface area 28.85 m²/kg) are relatively dense, fine-pored and heavy (Fig. 1).

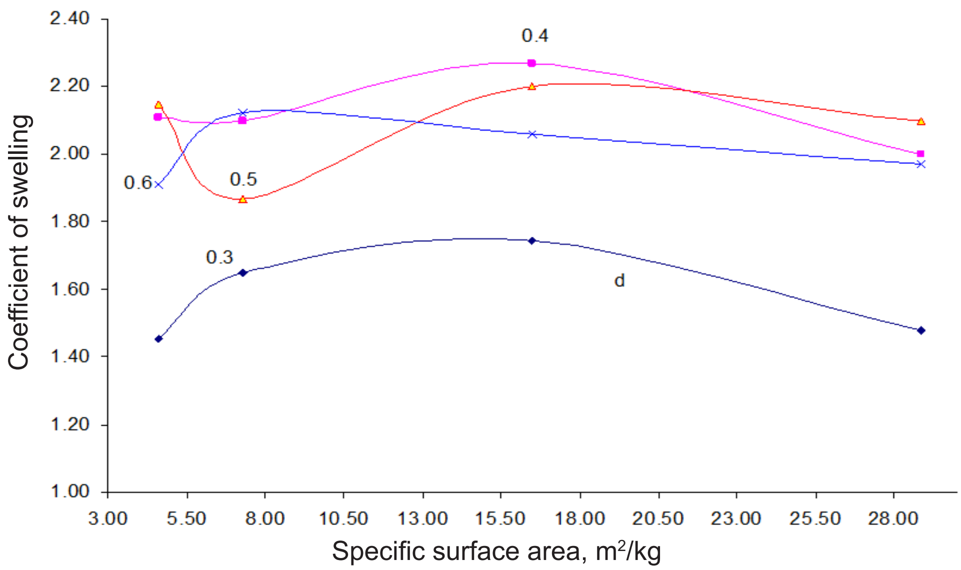

Figure 1: The effect of W/N and sand fineness on swelling

Table 2: Parameters of composition variation and test results

Sieve	Specific surface area	W/N	Alum, %	Swelling coef.	Shrink-age, %	Flow before	Flow after	Density before	Density after
0.5	4.62	0.3	0.2	1.45	6.25	7.5	18.3	1386.67	1270
0.5	4.62	0.4	0.2	2.27	8.47	16.5	25.5	846.3	746.3
0.5	4.62	0.5	0.2	2.21	0	28.5	-	756.45	661.29
0.5	4.62	0.6	0.2	1.91	1.54	33	-	828.81	708.47
0.316	7.30	0.3	0.2	1.65	1.19	8	18.8	1251.81	1153.01
0.316	7.30	0.4	0.2	2.10	4.76	17	26	902.50	786.25
0.316	7.30	0.5	0.2	1.87	8.93	20.5	26.5	952.94	878.43
0.316	7.30	0.6	0.2	2.13	0.00	34	-	747.06	660.3
0.14	16.48	0.3	0.2	1.75	4.17	6.9	21	1204.35	1108.70
0.14	16.48	0.4	0.2	2.17	6.41	13	25.5	927.40	798.63
0.14	16.48	0.5	0.2	2.14	1.67	25	28.5	838.98	762.71
0.14	16.48	0.6	0.2	2.06	0.00	28	-	779.41	701.47
0.08	28.85	0.3	0.2	1.48	2.94	-	-	1360.61	1224.24
0.08	28.85	0.4	0.2	2.00	2.00	-	-	909.28	789.69
0.08	28.85	0.5	0.2	2.14	0.00	-	-	816.39	701.64
0.08	28.85	0.6	0.2	-	-	-	-	-	-
0.5	4.62	0.3	2	-	-	7.5	18.3	-	-
0.5	4.62	0.4	2	-	-	16.5	25.5	-	-
0.5	4.62	0.5	2	-	-	28.5	-	-	-
0.5	4.62	0.6	2	-	-	33	-	-	-
0.316	7.30	0.3	2	1.40	4.76	8	18.8	1285	1175
0.316	7.30	0.4	2	1.60	4.17	17	26	1121.74	1017.39
0.316	7.30	0.5	2	1.65	0.00	20.5	26.5	916.28	830.23
0.316	7.30	0.55	2	2.28	1.52			776.92	732.31
0.316	7.30	0.6	2	2.58	10.59	34	-	676.32	597.37
0.316	7.30	0.65	2	2.73	4.44			594.19	555.81
0.316	7.30	0.7	2	1.42	5.88			699.28	586.96
0.14	16.48	0.3	2	1.17	5.71	6.9	21	790.91	718.18
0.14	16.48	0.4	2	1.75	0.00	13	25.5	971.43	914.29
0.14	16.48	0.5	2	2.19	2.36	25	28.5	770.97	695.16
0.14	16.48	0.55	2	2.48	0.00			785.00	691.67
0.14	16.48	0.6	2	2.32	4.55	28	-	676.53	558.73
0.14	16.48	0.65	2	2.72	4.60	-	-	590.36	556.63
0.14	16.48	0.7	2	2.77	5.15	-	-	561.96	527.17
0.08	28.85	0.3	2	-	-	-	-	-	-
0.08	28.85	0.4	2	-	-	-	-	-	-
0.08	28.85	0.5	2	2.00	3.45	-	-	839.29	750.00
0.08	28.85	0.6	2	-	-	-	-	-	

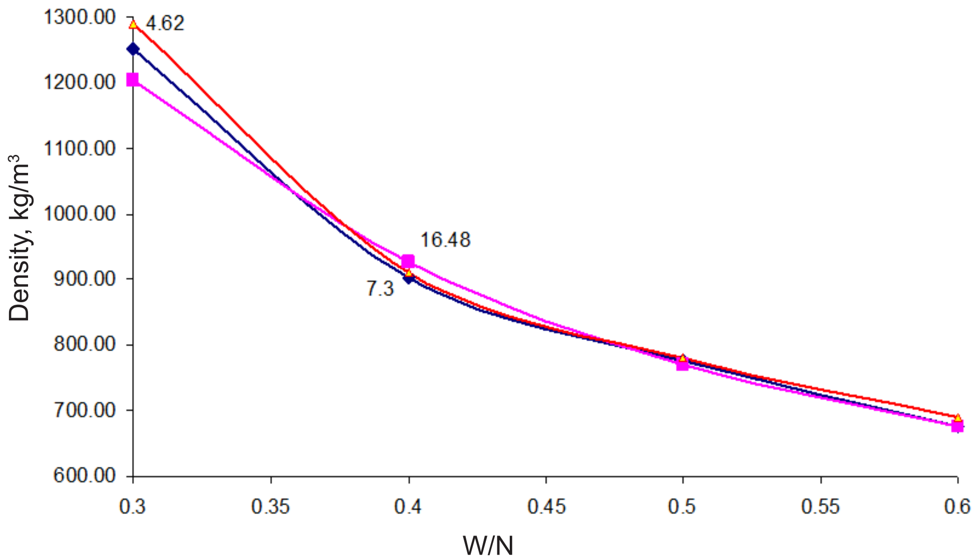

Figure 2: The effect of W/N and sand fineness on density

The content of aluminum powder in a 2% by weight of the total mixture leads to a very fast and intensive blowout, which complicates the product forming. The content of aluminum powder in the 0.2% mixture helps to slow down the chemical reaction inside the solution and delay the onset of blowout by 10-15 minutes, as well as uniform blowout throughout the entire volume of the product.

Porous concrete with B5 and B3.5 strength class and F25 freeze-thaw resistance was obtained on the aerated concrete mixes considered (Fig. 2).

Selection of a gas-forming agent and a binder in aerated concrete

The technical and economic efficiency of construction is enhanced by a reduction in the cost of structures due to the disposal of industrial waste, the use of energy-saving technologies, and the rational use of labor resources [12-16].

In connection with the foregoing, it was carried out a series of studies on the development of mixes for the production of aerated concrete with a density of 450-750 kg/m³ at the Department of Construction and Heat, Water and Gas Supply. It was used white Portland cement with an activity of 40 MPa, as fillers – ash from thermal power plants, ground slag of metallurgical production and basalt screening dust. The water-glass to ensure the viscosity of the system and calcium polysulfide addition to provide a quick and high strength gain was used [17-22].

Dry hydrated lime was introduced into the raw mix; PAK-3 aluminum powder and calcium hydroxide were used to intensify gas formation during the reaction. The consumption of dry hydrated lime was 2-2.5 hours of aluminum powder consumption.

The calcium polysulfide solution was used with a density of 1.2 g/cm³ in an amount of 6-12% wt of cement. Water-glass was characterized by a density of 1.25-1.3 g/cm³ with a module of 2.5-2.7. Its consumption was 7-11% wt of cement. The calcium polysulfide addition and water-glass contribute to a better gas-retaining property of the mixture (Table 3).

Table 3: The composition of the developed mixtures

Materials	Composition, % wt							
	1	2	3	4	5	6	7	8
Portland cement	40	41	35	36	35	38	31	33.4
TTP ash	-	-	17.7	14.85	-	-	15	-
Basalt screening dust	16.7	18.1	23	25.7	18.4	16.44	-	13
Ground slag	-	-	-	-	15.1	15.5	16.5	21
Dry hydrated lime	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Aluminum powder	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06
Calcium polysulfide addition	-	5.05	-	4.1	-	3.8	-	-
Water-glass	-	-	-	-	-	-	3	2.4
Water	43.05	35.6	24.05	20.1	31	26	34	30

Table 4: Physical and mechanical properties of aerated concrete

Properties	Composition, % wt							
	1	2	3	4	5	6	7	8
Average density in the dry state, kg/m³	450	450	550	550	700	700	750	750
Ultimate compressive strength, MPa	0.9	1.5	1.4	2.5	2.9	3.8	3.1	4.9
Coefficient of heat conductivity, W/(m·oC)	0.183	0.2	0.19	0.2	0.23	0.23	0.23	0.26
Water absorption, %	47	45	39	38	33	32	31	30

When preparing the raw mix, it was loaded filler, binder and part of the water into the mixing batch. After stirring for 1-1.5 min, an aqueous slurry of lime and a mixture of aluminum powder with calcium polysulfide were added. After 2-2.5 minutes of stirring, the mixture was discharged into shapes. During the preparation of the mixture, unheated water with a temperature of 30-35 °C was used. Samples of aerated concrete solidified under natural conditions at a temperature of 12-16 °C. The results of physical and mechanical properties are shown in Table 4.

Optimization of the developed compositions

The aim of this work is to develop and optimize the composition of lightweight concrete using gypsum building plaster as a binder. Commercial lignosulfonate was introduced into the concrete as a water-reducing admixture, and sodium tripolyphosphate was used as a retarding agent. Expanded clay and wood sawdust were used as fillers. To determine the optimal grain composition of expanded clay affecting the strength of concrete in each series of experiments, monofractions were used: fraction of 20-40, 10-20, 5-10, 0.14-5 mm. In total, five series of experiments were carried out, four – with expanded clay and one series with sawdust.

As factors affecting the strength of concrete, within each series, X_1 was considered as cement consumption in kg per m³; X_2 is a solid-liquid ratio; X_3 is volume fraction of filler in %. The factors varied in accordance with Table 5. Six 4x4x416 cm bars and four 10x10x10 cm cubes were made from aerated concrete of each composition. Vibration was used on the shaker apparatus during manufacture, and then the dismantled samples were dried to constant weight and tested for bending and compression.

Table 5: The levels of factors variation

Factors	Levels of variation		
	-1	0	+1
X_1	1150	1250	1350
X_2	2.23	2.5	2.87
X_3	25	35	45

For each series of experiments, a regression analysis of a three-factor quadratic model in the form of polynomial of second degree was performed [23-26]. To describe all the experiments with expanded clay, a four-factor model was used, where the expanded clay strength (in the cylinder) was used as the fourth factor.

When processing a series of experiments with slag sand, the following regression equations were obtained (Eqs. 1-2):

$$R_{wg} = 121,3 + 8,2X_1 - 6,3X_2 - 7,3X_3 + 35,7X_1^2 - 18,8X_2^2 - 13,1X_3^2 - 25,3X_2X_3 \quad (1)$$

$$R_{made} = 28,2 - 3,1X_2 - 4,3X_3 - 5,3X_2X_3, \quad (2)$$

When using expanded clay fractions of 5-10 mm, regression analysis showed the following (Eq. 3):

$$R_{wg} = 184,6 + 15,2X_2 - 30,1X_2^2 - 16,7X_3^2 + 10X_1X_2;$$

$$R_{made} = 45,78 \quad (3)$$

When using expanded clay fraction of 10-20 mm, the following regression equations were obtained (Eqs. 4-5):

$$R_{wg} = 141,05 + 8,2X_1 + 18,7X_1^2 - 20,3X_3^2 + 9,3X_1X_2 - 10,48X_2X_3 \quad (4)$$

$$R_{made} = 29,9 + 3,2X_1X_2, \quad (5)$$

When processing a series of experiments with expanded clay fractions of 20-40 mm, the following regression equations were obtained (Eq. 6):

$$R_{wg} = 41,15 + 4,6X_1 - 5,1X_2 + 10,4X_1^2 - 9,3X_2^2 + 6,3X_1X_2; R_{made} = 9,1 \quad (6)$$

The use of sawdust made it possible to obtain the following equations (Eqs. 7-8):

$$R_{wg} = 115,27 + 4,6X_1 + 17,2X_2 - 41,8X_2^2 - 3,87X_1X_2 \quad (7)$$

$$R_{made} = 47,3 - 7,1X_2 + 10,1X_1^2 - 28,42 \quad (8)$$

When calculating the regression equations for all expanded clay fractions from a four-factor experiment, it was gotten (Eqs. 9-10):

$$R_{wg} = 104,5 + 18,02X_4 - 18,4X_2^2 - 0,21X_4^2 - 10,03X_2X_3, \quad (9)$$

$$R_{made} = -4,3 - 1,2X_3 + 5,2X_4 - 1,04X_4^2 - 2,31X_2X_3 \quad (10)$$

The resulting models were tested for adequacy by the Student t-test and Fisher's ratio test. Equation (7) turned out to be inadequate according to the F-test; the remaining equations passed the test.

CONCLUSIONS

The experimental data and the results of their mathematical processing led to the following conclusions. Expanded clay aggregate and sawdust for gypsum-lightweight concrete are active and contribute to its hardening. The maximum strength with a change in the filling material proportion within 25-45% is observed at the volume fraction of filler in 29-32%. This is explained by the fact that these compositions are more optimal in terms of water-need.

The calcium polysulfide addition helps to reduce the amount of mixing water and improve the physical and mechanical properties of aerated concrete. The addition of water-glass due to chemical interaction with clinker minerals and subsequent crystalline neoplasms also favorably affects the properties of aerated concrete.

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