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STRENGTH TESTS OF CONCRETE CUBES WITH ADDITION OF ANTHROPOGENIC WASTE

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ABSTRACT: The authors have studied the development of a high-strength concrete mixture for manufacturing reinforced concrete products, in particular, the bar lintels. Dump fly ash of the Pavlodar CHPP-1 has been added as man-made waste. The paper presents the results of testing the concrete cubes strength with addition of industrial waste. The test results show the possibility of using anthropogenic waste for concrete mix in manufacturing bar lintels. In this case, the longer the hardening time, the higher the concrete mixture strength. By planning the experiment, a linear mathematical dependence of the concrete strength on such studied factors as cement, man-made waste and water, was obtained. The adequacy of the obtained model is confirmed by comparing the tabular and calculated values of the Fisher coefficient, as well as the coefficient of determination, which in practice varies for mixtures in the range from 0.7 to 0.8. According to the Pareto diagram, it is determined that all the factors are important, but the first component, i.e. cement consumption has the greatest effect. As a result, it was found that the addition of 10 % of man-made waste can reduce cement consumption by 10 % and increase the product strength by 20 %.

Keywords: Anthropogenic Waste, Concrete Mix, Concrete Strength, Bar Lintel, Cement.

1. INTRODUCTION AND RELEVANCE OF THE STUDY

The problem of the integrated use of industrial waste is acquiring great significance as an important reserve of increasing the production efficiency [1]. The processing of anthropogenic waste into building materials is an important economic lever in the production of alumina, it provides employment for the population in new industries, and gives a tangible impetus to the economic development of the region as a whole [2]. The analysis of scientific and technical literature revealed a wide range of possible applications of alumina production manufacturing sludge [3], primarily in the production of building materials and products [4]: as a raw material to produce Portland cement clinker [5], as a mineral additive to cement [6], as an independent binder for concretes and mortars of normal and autoclave hardening [7], as a filler for concrete mixes [8]. The advantage of binders based on bauxite slimes over cement or cement-concrete (cement-mineral mixtures) slimes is the absence of fast setting and slower hardening processes [9]. If, when working with materials reinforced with cement, the time between the preparation of the mixture and its compaction usually should not exceed 4-6 hours, otherwise the quality of the layer being arranged decreases sharply, but when using slurry binders this time it can reach up to 3 days. This in turn will allow to increase the length of the shift gripper, to expand the scope of work, to increase productivity, and to eliminate the negative impact on the material final strength of unforeseen stops in the technological regulations associated with equipment breakdown or delayed delivery of the mixture. The Bayer sludge is widely used abroad: in Germany, France, Great Britain, Australia, India, Hungary, Japan, Taiwan, Brazil, etc. [10]. In France, studies have shown the possibility of using slurry concrete in mortars and pressed fittings of high density and strength [10]. Researches in the UK have developed a cement technology based on bauxite sludge and rude chalk [10]. The Vereinigte Aluminium-Werke Company (Germany) uses slime in the production of expanded clay to reduce the sintering temperature of the charge [10]. Construction companies in Japan obtain concrete mixtures for road construction and various compositions to produce pressed wall products based on sludge [10]. Brazilian scientists have investigated the use of fly ash mineral coal as a raw material in the production of ceramic tiles [11]. The US scientists in [12] note the possibility of using ash as a soil additive through seepage and contamination of ground water. Australian [10] and Indian [13] researchers have established that bauxite slurry mixed with carbonaceous shale is suitable for manufacturing facing tiles, pigments, varnishes. The developments of building materials based on sludge available today are not related by a common trend, they are insufficiently systematized.

All this raises an urgent need for targeted comprehensive studies of both the sludge itself and the materials based on it. It can be stated that developing and studying various building materials based on sludge are carried out very actively both in our country and abroad. However, the problem of utilization of sludge in construction continues to remain relevant, since almost all the studies were completed only at the stage of experimental development. Bauxite sludge allows improving the mixture workability, increasing strength, and reducing the cost of concrete by replacing a part of the sand and cement. This research presents the results of strength tests of concrete cubes with addition of anthropogenic waste.

2. RESEARCH SIGNIFICANCE

Utilization of man-made waste in the production of building materials is gradually becoming a national problem. The growing mountains of waste litter the habitat. In addition, the day when the shortage of raw materials will slow down the pace of construction is not far off. In this regard, studying the possibility of using dry ash and ash-and-slag mixtures from dumps in the production of prefabricated reinforced concrete structures, in particular bar lintels, is of great scientific and practical importance for the construction industry of the Republic of Kazakhstan.

3. METHODS OF STUDY, EQUIPMENT AND MATERIALS

Strength tests were carried out in accordance with State Standard 10180-2012 to study the concrete mixture with the addition of industrial waste applicability in manufacturing bar lintels. Testing of cube samples with different contents of anthropogenic waste was carried out in the laboratories of the NORD Prom NS LLP in Temirtau. Anthropogenic waste was obtained from the EkostroyNII-PV LLP. In the laboratory conditions, the kinetics of strength gain was studied under natural conditions of hardening and after heat and moisture treatment (HMT). The HMT modes are as follows: the total duration is 8 hours, the temperature rises from 20 to 70 0C within 4 hours, the isothermal exposure is at 70 ^{0}C within 4 hours. For manufacturing a concrete mix (for sample cubes), the following materials were used: cement PC400D20 produced by the CENTRAL ASIA CEMENT JSC, crushed stone with the fraction of 5 ÷ 20 mm produced by the Tekhnoindustriya LLP, large sand produced by the Sary-Arka Zholdary LLP. The requirements for concrete are as follows: mobility, P1 (1÷4cm); the M-200 concrete grade for compressive strength. Dump fly ash from the Pavlodar CHPP-1 was added as the anthropogenic waste. The chemical composition of dump fly ash from the Pavlodar CHPP-1 is shown in Table 1.

For testing, 4 compositions were worked out.

Table 1 Chemical composition of dump fly ash, %.

SiO_2	Al_2O_3	TiO_2	Fe_2O_3	CaO	MgO
60,6	28,6	1,4	5,4	2	0,5
K_2O	Na_2O	P_2O_5	MnO	MnO	Side impurities
0,5	0,2	0,7	0,1	0,1	7

When determining the rate of consumption of materials, the rate of consumption of materials to produce prefabricated reinforced concrete at the Karagandastroykonstruktsiya LLP was adopted as the basis (see Table 2).

Table 2 Norms of consumption of materials in the production of precast concrete according to "Karagandastroykonstruktsiya" LLP

Samples number	Techno-genic waste, %	Brand of concrete	Material consumption per 1 m^3			
			Cement, kg	Sand, kg	Crushed stone, kg	Water, l
1	0	200	300	1200	640	185
2	20	200	244	1200	640	180
3	15	200	260	1200	640	178
4	10	200	270	1200	640	176

Weighing dry materials when preparing the concrete mixture according to the above compositions was carried out on a CAS AD bench scale. A SNOL 67/350 low-temperature laboratory electric furnace was used to dry the cubes. Mixing dry materials was performed with the use of a BL-10 concrete mixer. Compaction of the cube samples was carried out using a vibrating table SMZh-539. The strength test of the cube specimens was carried out on a press for testing building materials.

4. PLANNING THE STUDY AND PREPARING SAMPLES FOR TESTING

The mortar component of concrete strength depends on such factors as cement consumption, waste and water content, which in turn determine the workability of the concrete mixture. The condition of concrete hardening is very important for ensuring the concrete strength [14].

The complexity of this experiment consists in selecting the optimal composition of the mixture, so that the sum of the fractions of the components is equal to 100 %, in addition, the resulting mixture should best meet a certain quality criterion [15]. We use the Statistics program to plan the experiment. In the "Plans for mixtures" procedure, two types of experiment plans were implemented: simplex-vertex; simplex-centroid plans. These plans evaluate the response surfaces at the vertices of the triangle and at the midpoints of the sides. For accuracy, additional interior points can be added to the plans. In our case, when planning experiments with a mixture, there are limitations on the proportions of the mixture components from below and from above. Our concrete mix consists of three components: cement, waste and water. At this, cement there should make 244-300 kg of the total amount of the mixture (485 kg); waste should be 0…56 kg, water should be within 176…187 kg (l). Under such conditions, standard simplex-vertex or simplex-centroid plans can no longer be generated, but they can be generated in the constrained surface and mixture designs module [15].

In view of the above, the following factors were taken as variable parameters: X_1 - cement consumption A, kg; X_2 - waste consumption B, kg; X_3 - water C, kg.

In the start dialog of the "Plans for mixtures" module, we make settings in accordance with the limitations and click on OK, the program builds a three-factor simplex-vertex plan. Now, by the experiments carried out according to the plan, we will write down the results in an additional column. The results of the experiments (response function) will be compressive strength R_{comp} (Table 3) [15]

Table 3 Plan and result of the experiment

Level of variation	Cement, A	Technogenic waste, B	Water, C	R_{comp} MPa
1	300	0	185	34,22
2	244	56	185	28,42
3	300	9	176	36,36
4	260	42	183	30,68
5	298	0	187	33,17
6	244	54	187	28,53
7	299	0	186	33,37
8	244	55	186	28,21
9	300	4,5	180,5	35,62
10	248,5	56	180,5	30,69
11	276,5	32,5	176	35,12
12	270	28	187	35,5
13	273,1667	29,16667	182,66	33,9

Let us determine the moisture content of sand and weigh it. Then it is dried in a low-temperature laboratory electric furnace SNOL 67/350. The range of automatic temperature control is from 50 to 350 ^{0}C.

The temperature stability in the set mode is 2 ^{0}C. After weighing dry materials, we place them in turn in the BL-10 concrete mixer and mix within 40-60 seconds. After the time expiration, cubes are filled with the ready-made concrete mixture and compacted using a vibrating table SMZH-539. The purity of vibrations is 2800 vibrations/min, the amplitude is from 0.15 to 1.0 mm. Figure 1 shows the obtained sample cubes made of the concrete mixture with the addition of industrial waste.

Fig. 1 Accomplished samples-cubes of concrete mix with the addition of man-made waste: 1 - control sample, without additives; 2 – with the addition of 20% of man-made waste; 3 – with the addition of 15% of man-made waste; 4 – with the addition of 10% of man-made waste

5. TESTING SAMPLE CUBES FOR STRENGTH

The sample cubes are weighed and tested for strength using a press for testing building materials, the upper limit of load measurement is 1800 kN. The prepared sample cubes made of the concrete mixture with the addition of anthropogenic waste were tested in accordance with State Standard 10180-2012. The sample cubes were tested in three stages: after 1, 3 and 28 days. Figure 2 shows the prepared sample cubes and the testing process.

The conditions for hardening of the cube specimens are as follows: after 1 day in the steaming chamber; after 3 days in the natural conditions; after 28 days in the normal hardening room (after steaming and natural conditions).

Figure 3 shows the strength test process and some sample cubes after testing.

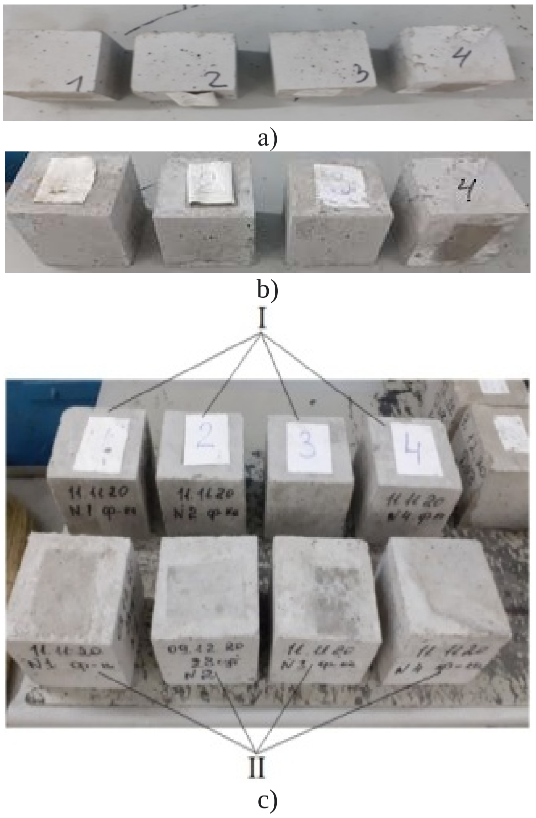

Fig. 2 Test cube samples obtained after steaming: a - after steaming (after 1 day); b - after 3 days; c - after 28 days; I – normal hardening room (after steaming); II - normal hardening room (natural conditions)

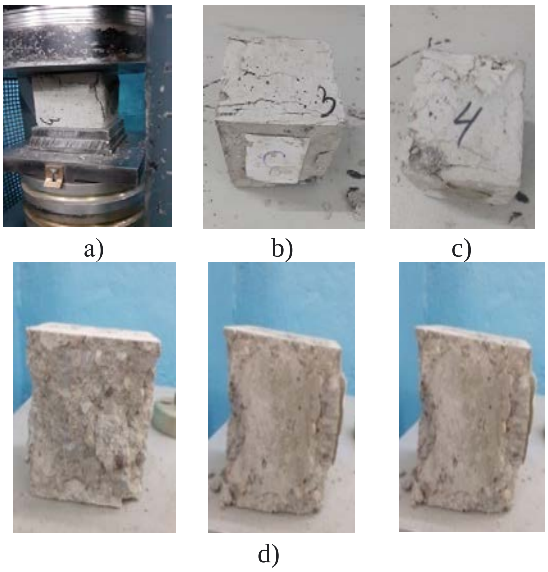

Fig. 3 Strength testing process and some samples-cubes after the test: a – the strength test process; b - the tested sample-the cube after steaming (after 1 day); c - the tested sample-the cube after 3 days; d - the tested samples-the cubes after 28 days

The results of testing for compressive strength of the sample cubes are summarized in Table 4.

Table 4 Results of testing for compressive strength of the sample cubes

Number structure	Test date	Curing conditions	Density, kg/m^3	R$_{сж}$, MPa
After steaming. After 1 day				
1	12.11.20.	Steaming chamber	2400	18
2	12.11.20.		2310	14,81
3	12.11.20.		2370	16,44
4	12.11.20.		2420	20,99
After 3 days				
1	14.11.20	Natural conditions	2370	14,39
2	14.11.20		2410	10,43
3	14.11.20		2370	13,64
4	14.11.20		2380	14,64
After 28 days				
1	9.12.20	Normal hardening room (after steaming and natural conditions)	2380	34,22
2	9.12.20		2300	28,42
3	9.12.20		2360	30,68
4	9.12.20		2380	35,5
1	9.12.20		2350	26,32
2	9.12.20		2340	23,17
3	9.12.20		2350	28,17
4	9.12.20		2440	31,8

Figure 4 shows a graph of the concrete mix strength dependence on the content of anthropogenic waste.

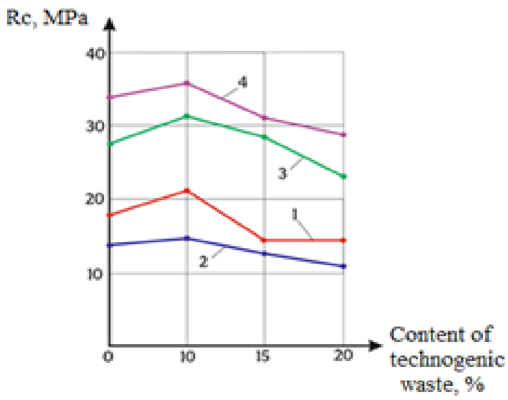

Fig. 4 Graph of the dependence of the strength of the concrete mixture on the content of technogenic waste: 1 - after 1 day in the steaming chamber; 2 – after 3 days in the natural conditions; 3 - after 28 days in the normal hardening room (after steaming); 4 - after 28 days in the normal hardening room (after steaming and natural conditions)

According to the test results, composition No. 4 with the use of anthropogenic waste in the amount of 10 % (of the mass of cement consumed per 1 m^3 of the concrete mixture) showed strength by 20 % more in comparison with the control composition at the age of 28 days.

After HWT at the age of 3 days, composition No. 4 also showed 16 % higher strength. These results are associated with the reduced W/C ratio compared to that of the

Table 5 Analysis of variance

Model	Dispersion analysis; Rc variable (trial+++); 3 factor plan for the mixture; total mixture value = 485, 13 experience; Sequential fitting of models of increasing complexity							
	SS Effect	Cc Effect	MS Effect	SS Mistake	cc Mistake	MS Mistake	F	P
linear	76,4413	2	38,22065	23,59549	10	2,359549	16,19829	0,000730
quadratic	18,1910	3	6,06367	5,40450	7	0,772071	7,85377	0,012135
spec. cubic	3,7431	1	3,74310	1,66140	6	0,276900	13,51785	0,010372
cubic	1,4205	3	0,47351	0,24087	3	0,080289	5,89763	0,089525
general corrected values	100,0368	12	8,33640					

other formulations. The graph in Figure 4 shows that increasing the percentage of anthropogenic waste has a negative effect on the concrete mixture strength. It has been found that at all the stages of the test, with the content of man-made waste at the level of 10 %, the concrete mixture strength increases (see Fig. 4, curves 1,2,3,4.). This proves that 10 % is the optimal amount of man-made waste content in the composition of the concrete mixture. Adding 10 % of anthropogenic waste can reduce cement consumption by 10 % and increase the product strength by 20 %.

6. ASSESSMENT OF THE ADEQUACY OF OBTAINED RESULTS

To check the adequacy of obtained results in the program, let us select the full linear model and go to the ANOVA tab – Variance analysis (Table 5). The analysis of variance allows assessing the adequacy of the model. The ANOVA procedure is designed in such a way that first the results of fitting the experimental data with the linear model are given, then the ones with the quadratic, special cubic, and full cubic models are given. It was obvious from the data that the agreement (adequacy) of the fitted surface is significant only for the linear model, since F reaches its maximum value (F_{calc} (3.13) = 16.19829> F_{tabl} (3.13) = 3.86, at α = 0.05), and the significance level p is 0.00073. But the value of the coefficient of determination R^2 (R-sq = 0.7641) that is interpreted as the proportion of variability of the dependent variable relative to the mean value explained by the regression model. Therefore, we will carry out further research for a linear model. The linear mathematical dependence of the concrete strength on the factors studied has the form:

$$R_{comp}(x,y,z) = 7.586164601763 \cdot x + 31.689571020189 \cdot y + 16.828267035537 \cdot z,$$

where x is the cement pseudo-component; y is the waste pseudo-component; z is the water pseudo-component.

It is advisable to rescale the initial values of the factors when analyzing plans for a mixture, so that the lower and upper values of the factors (with the standard simplex plan) are converted to 0 and +1, respectively. Namely, the component installations are recoded to so-called pseudo-components when analyzed at the user's request and they are calculated via the following formula:

$$x_i' = (x_i - L_i)/(Total - L),$$

where $x'i$ is the i-th pseudo-component; x_i is the initial component value; L_i is the base limitation (the boundary) of the i-th component; L is the sum of all the base limitations (boundaries) for all the components in the plan.

Total means the total sum for the mixture. According to the obtained mathematical model, by substituting the values of the pseudo-components into the equation on a scale of 0-1 (provided that x + y + z = 1), we obtain the predicted value of the compressive strength [15]. Table 6 presents the values of the pseudo-components in accordance with Table 5. It should be noted that this mathematical model works under the condition of the limitations indicated above. A Pareto chart is an effective tool for determining the effects of which factors contribute most to the dependent variable of interest – the response function.

Table 6 Table of pseudo-components

x	y	z
0,8615385	0	0,138462
0	0,861538	0,138462
0,8615385	0,138462	0
0,2461538	0,646154	0,107692
0,8307692	0	0,169231
0	0,830769	0,169231
0,8461538	0	0,153846
0	0,846154	0,153846
0,8615385	0,069231	0,069231
0,0692308	0,861538	0,069231
0,5	0,5	0
0,4	0,430769	0,169231
0,4487179	0,448718	0,102564

To build a Pareto chart, it is needed to click on the Pareto Effects Map button. It can be seen from the chart in Figure 5, that all the linear effects are important, but the most important is the first component.

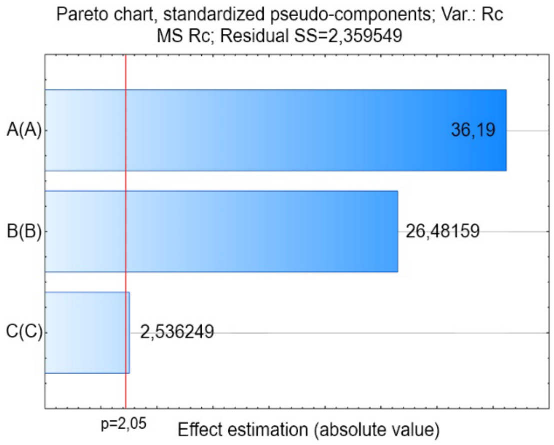

Fig. 5 Pareto chart

Let us illustrate the forecast results using the graph of the fitted response function (Figure 6), since we are talking about analyzing the relationship between the dependent variable (response) and factors in a triangular diagram.

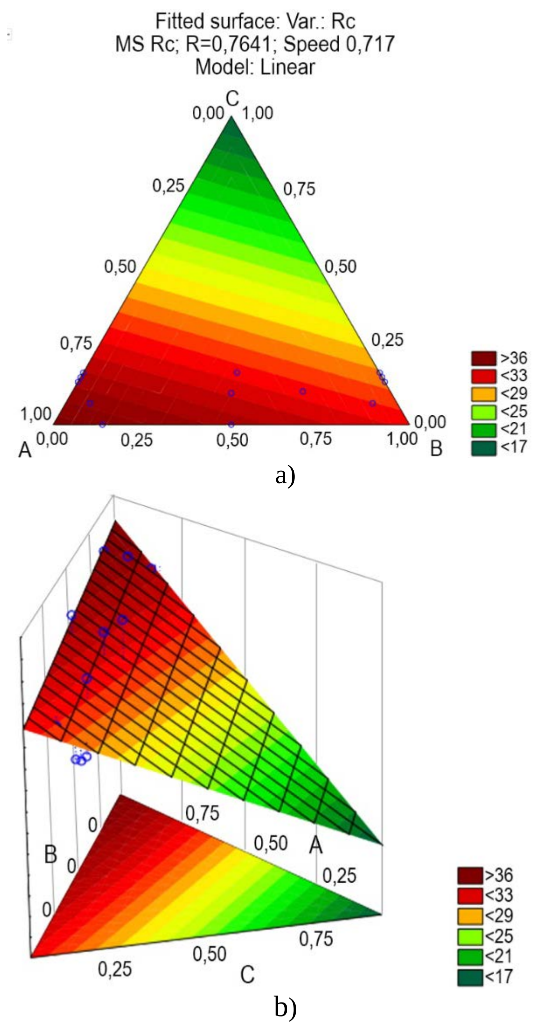

Fig. 6 Graph of the fitted response function: a) surface, b) space

Click on the Surface plot button, a window will appear in which it is needed to select the factors and the corresponding names of the axes: the sides of the triangle. As a result of planning the experiment for the mixture, a linear mathematical model and a response surface were obtained. The adequacy of the obtained model is confirmed by comparing the tabular and calculated values of the Fisher coefficient, as well as the coefficient of determination, which varies in the range from 0.7 to 0.8 for mixtures in practice. According to the Pareto chart, it was determined that all the factors were important, but the first component, i.e. cement consumption, had the greatest impact.

7. CONCLUSIONS

1. As a result of testing the concrete cubes strength with addition of anthropogenic waste, it was found that the addition of 10 % of anthropogenic waste can reduce cement consumption by 10 % and increase the product strength by 20 %.
2. Obtained results confirmed the possibility of using a concrete mixture with addition of industrial waste in manufacturing bar lintels of the 5PB27-27 and 5PB31-27 types.

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