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Assessment of the physical and mechanical characteristics of sand for the production of foam concrete using the two-stage foam injection method

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ABSTRACT

The article presents the results of experimental studies of the properties of quarry sand to assess their suitability for use in the production of foam concrete. The sites of quarry sand extraction in the territory of the Akmola region are analyzed and their physical and mechanical characteristics are characterized. Evaluation of the physical and mechanical characteristics of sand was made for four types of sand. The main evaluation parameters were: particle size distribution, homogeneity, shrinkage, density and moisture content of sands. The results of the study showed that the physical characteristics of sands vary depending on their type, which indicates the differences in the natural composition and properties of these materials. Evaluation of the homogeneity of the different types of sands confirms the significant differences between the types. The highest homogeneity (x_{max}=77.45; x_{max-1}=14.98; Cc=73.5%) was observed in type 1 sand, while type 4 sand shows the minimum degree of homogeneity (x_{max}=47.30; x_{max-1}=42.28; Cc=8.7%). According to the test results, the maximum values of both densities in type 2 are: ρ_d=1.519 g/cm^2, ρ_w=1.951 g/cm^2, and the minimum values of both densities in type 4 are: ρ_d=1.438 g/cm^2, ρ_w=1.894 g/cm^2. The maximum natural moisture content in Type 1 samples is vn=9.5%, while the minimum values are 7.6% and 7.2% (Type 2 and 4). The obtained private density values have a high degree of convergence because the coefficients of variation have very low values: for Type 1 sands are 0.1-0.3%; for Type 2 sands are 0.7-0.8%; for Type 3 sands are 0.5-0.7%; for Type 4 sands are 0.4-0.6% (variation of private density values of dry and wet sands, respectively). Analysis of the results of tests on the shrinkage of samples showed that the maximum shrinkage is observed for sands of type 1 equal to 15.63%, while the minimum shrinkage is characteristic of samples of type 3 and 4 (11.25% and 11.88%). Taking into account the suitability of sand for the production of foam concrete, the most preferable is Type 1 sand mined in the Eltok building sand deposit.

Keywords: sand, foam concrete, physical and mechanical characteristics, shrinkage, particle size distribution, degree of homogeneity.

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Introduction

In the context of the rapid development of the construction industry, a variety of building materials have appeared, and one of the most interesting and promising of them is foam concrete [[1], [2], [3]]. The relevance of this study is due to the high demand for foam concrete in the modern construction market. Foamed concrete is characterized by a variety of physical and mechanical characteristics, ease of production, relative economy and small mass of blocks, which makes it very attractive for use in construction [[4], [5], [6]]. Special interest in this material is caused by its unique properties, such as density, thermal conductivity and features of the cellular structure.

One of the main characteristics of foam concrete is its porous structure [7], which makes it an ideal material for a wide range of construction applications.

Foamed concrete belongs to promising building materials and has several significant functional properties that favorably distinguish it from heavy and lightweight concrete: low thermal conductivity, good vapor permeability, low energy costs for its production, good sound insulation, environmental friendliness, durability, and fire safety. In recent years, foam concrete has been widely used in construction as a heat-insulating and structural-insulating material.

In modern conditions, there are a variety of raw materials that can be used in the production of foam concrete. The process of making foam concrete consists of the integration of ready-made foam into the cement-sand mixture, which contributes to the creation of a closed pore system [[8], [9]]. It is important to note that the quality and characteristics of the components used are critical to ensure the required strength of foam concrete. Even minor use of low-quality aggregates can lead to a decrease in the strength of foam concrete structures [[10], [11], [12]]. Therefore, the selection and quality of raw materials play a crucial role in the production of foam concrete.

An important aspect is the durability of cellular concrete, the basis of which is cement binder and fine aggregate [13]. One of the key factors determining the quality of sand is the ratio of different fractions of its grains [[14], [15]]. In the production of foamed concrete, fine and very fine sand is used, and sometimes this sand may contain harmful impurities such as sulfur and sulfuric acid compounds, mica, and amorphous modifications of silica. The latter is especially dangerous, as they can interact with alkalis and cause destruction of the cement matrix. Therefore, control of sand quality and its composition is important to ensure the durability and reliability of foam concrete structures [[16], [17], [18], [19], [20]].

The purpose of this study is to conduct a comparative analysis of the physical and mechanical characteristics of quarry sand to assess its suitability for further use in the production of foam concrete.

Experimental technique

Based on the results of the analysis of the market of non-metallic building materials (sand) in Astana city, samples of raw materials were selected for testing. The list of selected samples includes the following quarries:

Type 1. Eltok sand deposit is located in Arshalyn district of Akmola region near Volgodonovka village, 44 km southeast of Astana city.

Type 2. Aryktynskoe sand deposit is located in Korgalzhyn district of Akmola region 1.5 km north of Arykty village, 40 km east of Korgalzhyno village, 100 km south-west of Astana city.

Type 3: Sensembay sand deposit is located in Arshalyn district of Akmola region, 1.5 km north-west of Volgodonovka village.

Type 4. Zhana-Zhol sand deposit is located in the Tselinograd district of Akmola region, 1.0 km southwest of Karazhar village and 30 km southwest of Astana city.

The main research indicator of sand is the evaluation of its particle size distribution, exactly the determination of clay particles in its composition, possible dust-like impurities and inclusions affecting the quality of the manufactured product - foam concrete. The tests are carried out under conditions of statistical evaluation of this indicator, i.e., at least 100 kg of sand will be selected to evaluate each type, which is more than 20 samples for each of the three types of sand being compared. Subsequently, the sand sieved by particle size distribution will be used to evaluate the quality of cement, instead of polyfractional sand. The sand composition for cement evaluation will be selected based on average statistical data of granulometric analysis of the type of sand to be selected for use in production. In the end, we will get the results of the activity and setting time of cement under the conditions of its interaction with real components that will be used in the production of foam concrete.

Additional tests of sand will be unregulated shrinkage tests of sand shrinkage during soaking. The amount of shrinkage will give us an understanding of the potential change in the volume of the final product relative to the initial product, which may be useful when pouring large-scale structures (in further performance studies and possible formulation adjustments for a mobile plant).

Sand studies include the following sequence of activities:

- sampling of each of the three types of sand to be compared, weighing at least 100 kg;
- washing the sand with hot water and measuring the mass (before and after washing) using a 0.05 sieve (when draining the water);

- carrying out tests of particle size distribution according to aggregated indicators: dust particles 0-0,05 mm (residue on the pallet); fine sand 0,05-0,25 mm (residue of sieve 0,05); medium sand 0,25-0,5 (residue of sieve 0,25); coarse sand 0,5-2,0 mm (residue of sieve 0,5); gravel >2,0 (residue of sieve 2,0), according to the test method regulated by GOST 8735
- analysis of the obtained granulometric (grain) composition, with the selection of the optimal type of sand suitable for the production of foam concrete;
- evaluation of sand shrinkage, as well as evaluation of sand densities to determine the dosage: bulk density, density in dry state, wet state, etc.

The sample tests for the evaluation of natural indices were performed for selected samples, immediately after transportation. However, to determine the density in the dry and water-saturated state, a preliminary quartering was performed (Figure 1), the purpose of which was to obtain results as close as possible to the average statistical indicators with a minimum number of tests (in our case, 5 tests of each type). After quartering, 1000 ml samples were taken (for more convenient density estimation).

Sand shrinkage was assessed using the soaking method, Figure 2. The sequence of work included:

- a sampling of the compared soil types, totaling at least 15 kg for each of the sand types;
- determination of sand density at natural moisture content;
- drying the samples to a constant mass;
- determination of the density of dry sand;
- Soaking of sand with the determination of shrinkage and density in a water-saturated state.

Soaking of sand samples was carried out in a measuring container with a graduated scale until complete stabilization (constant value) of sand shrinkage, Figure 2. The weighing of samples was carried out on calibrated scales.

This methodology allowed us to conduct a subsequent comparative analysis of the qualitative characteristics of the studied sands in the context of their applicability in the production of foam concrete products.

Results and Discussion

Tabulated data of sand grain size distributions are presented in Tables 1-4, which were compiled to investigate the fractional composition of each of the studied sands in more detail.

Figure 1 - Sand tests

Figure 2 - Evaluation of sand shrinkage

Table 1 - Results of granulometric composition of Type 1 sands

Sample number	Weight of sand in a sieve					Sample mass		Loss, %
	Sieve 1 d=2 mm	Sieve 2 d=0.5 mm	Sieve 3 d=0.25 mm	Sieve 4 d=0.05 mm	Residue >0.05 mm	After	Before	
1	27	300	3760	919	4	5010	5010	0.000
2	30	311	4059	866	4	5270	5270	0.000
3	25	308	3917	786	3	5039	5040	0.020
4	35	297	3813	872	2	5019	5020	0.020
5	24	324	3797	854	5	5004	5005	0.020
6	21	350	3934	700	4	5009	5010	0.020
7	22	429	3805	739	5	5000	5000	0.000
8	25	358	3997	631	4	5015	5015	0.000
9	40	373	3955	646	4	5018	5020	0.040
10	25	349	3938	688	4	5004	5005	0.020
11	35	375	3942	661	4	5017	5020	0.060
12	30	398	3762	671	4	4865	4865	0.000
Average	28	348	3890	753	4	5023	5023	0.017
Deviation	6	42	99	102	1	-	-	-
Variation, %	21	12	3	14	20	-	-	-

Table 2 - Results of granulometric composition of Type 2 sands

Sample number	Weight of sand in a sieve					Sample mass		Loss, %
	Sieve 1 d=2 mm	Sieve 2 d=0.5 mm	Sieve 3 d=0.25 mm	Sieve 4 d=0.05 mm	Residue >0.05 mm	After	Before	
1	387	783	2613	1235	2	5020	5020	0.000
2	421	820	2588	1178	6	5013	5015	0.000
3	345	756	2646	1257	5	5009	5010	0.020
4	389	815	2506	1294	5	5009	5010	0.020
5	311	810	2720	1167	7	5015	5015	0.020
6	402	789	2522	1289	3	5005	5005	0.020
7	367	793	2558	1302	3	5023	5025	0.000
8	379	738	2618	1275	4	5014	5015	0.000
9	328	816	2637	1228	3	5012	5015	0.040
10	354	718	2740	1195	6	5013	5015	0.020
11	387	785	2658	1189	5	5024	5025	0.060
12	404	766	2642	1204	3	5019	5020	0.000
Average	373	782	2621	1234	4	5015	5016	0.017
Deviation	33	32	71	48	2	-	-	-
Variation, %	9	4	3	4	36	-	-	-

Table 3 - Results of granulometric composition of Type 3 sands

Sample number	Weight of sand in sieve					Sample mass		Loss, %
	Sieve 1 d=2 mm	Sieve 2 d=0.5 mm	Sieve 3 d=0.25 mm	Sieve 4 d=0.05 mm	Residue >0.05 mm	After	Before	
1	45	1782	2419	761	2	5009	5010	0.000
2	42	1653	2500	812	3	5010	5010	0.000
3	32	1735	2584	655	3	5009	5010	0.020
4	37	1758	2496	711	3	5005	5005	0.020
5	31	1733	2528	719	3	5014	5015	0.020
6	26	1672	2531	772	2	5003	5005	0.020
7	36	1645	2570	753	3	5007	5010	0.000
8	38	1812	2379	782	2	5013	5015	0.000
9	42	1741	2469	756	2	5010	5010	0.040
10	34	1795	2468	699	4	5000	5000	0.020
11	33	1776	2454	737	2	5002	5005	0.060
12	38	1649	2566	756	3	5012	5015	0.000
Average	36	1729	2497	743	3	5023	5010	0.017
Deviation	5	60	63	42	1	-	-	-
Variation, %	15	3	3	6	24	-	-	-

Table 4 - Results of granulometric composition of Type 4 sands

Sample number	Weight of sand in sieve					Sample mass		Loss, %
	Sieve 1 d=2 mm	Sieve 2 d=0.5 mm	Sieve 3 d=0.25 mm	Sieve 4 d=0.05 mm	Residue >0.05 mm	After	Before	
1	12	2134	2340	516	8	5010	5010	0.000
2	17	2009	2527	452	5	5010	5010	0.000
3	21	2067	2406	511	7	5012	5015	0.020
4	14	2178	2249	567	7	5015	5015	0.020
5	18	2113	2328	538	5	5002	5005	0.020
6	14	2016	2398	576	5	5009	5010	0.020
7	19	2231	2310	453	6	5019	5020	0.000
8	23	2166	2387	428	5	5009	5010	0.000
9	15	2095	2415	475	5	5005	5005	0.040
10	21	2154	2303	526	5	5009	5010	0.020
11	19	2183	2305	497	6	5010	5010	0.060
12	16	2075	2470	442	5	5008	5010	0.000
Average	17	2118	2370	498	6	5015	5015	0.017
Deviation	3	69	79	49	1	-	-	-
Variation, %	19	3	3	10	18	-	-	-

Analysis of the data presented in the tables allows us to make the following observations:

- The average particle size for each of the studied sand types has different characteristics. It varies from 28 to 3890 for Type 1, 373 to 2621 for Type 2, 36 to 2497 for Type 3, and 17 to 2370 for Type 4.

- The deviation from the mean particle size also varies by sand type. For Type 1, the deviation ranges from 6 to 102, for Type 2 from 32 to 71, for Type 3 from 5 to 63, and for Type 4 from 3 to 79. This indicates a considerable diversity of fractions in each type.

- The variation in the mass of the material ranges from 3 to 21%, indicating that there is considerable variability in the composition of the sand in the different types.

- The percentage of material loss during sieving is small at less than 0.1%, indicating that the sieving procedure is effective and has little effect on the total amount of material.

Tables 5-8 show the results of the percentage of particle size distribution of the compared sands.

Table 5 - Percentage of particle size distribution of Type 1 sands

Sample number	Granules percentage, %				
	Sieve 1 d=2 mm	Sieve 2 d=0.5 mm	Sieve 3 d=0.25 mm	Sieve 4 d=0.05 mm	Residue >0.05 mm
1	0.54	5.99	75.05	18.34	0.08
2	0.57	5.90	77.02	16.43	0.08
3	0.50	6.11	77.73	15.60	0.06
4	0.70	5.92	75.97	17.37	0.04
5	0.48	6.47	75.88	17.07	0.10
6	0.42	6.99	78.54	13.97	0.08
7	0.44	8.58	76.10	14.78	0.10
8	0.50	7.14	79.70	12.58	0.08
9	0.80	7.43	78.82	12.87	0.08
10	0.50	6.97	78.70	13.75	0.08
11	0.70	7.47	78.57	13.18	0.08
12	0.62	8.18	77.33	13.79	0.08
Average	00.56	6.93	77.45	14.98	0.08

Table 6 - Percentage of particle size distribution of Type 2 sands

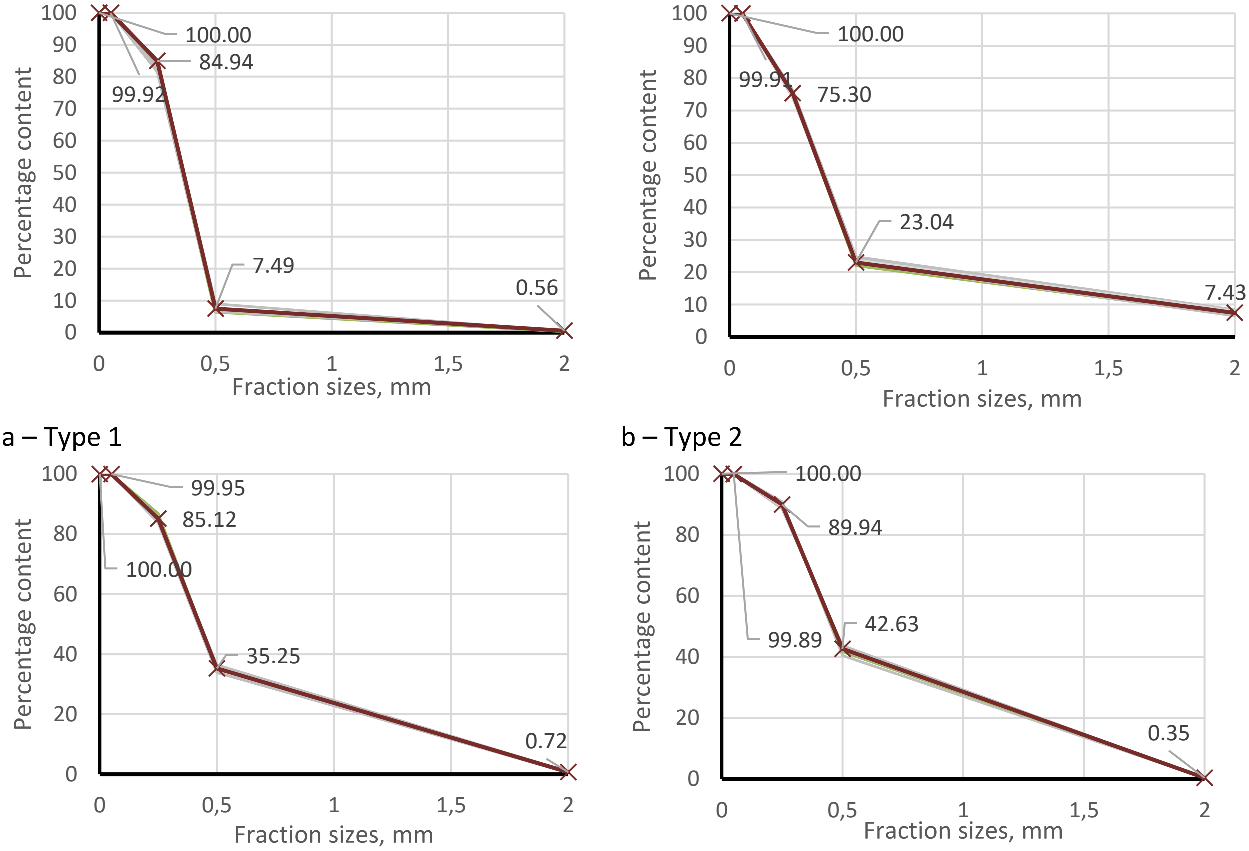
Sample number	Granules percentage, %				
	Sieve 1 d=2 mm	Sieve 2 d=0.5 mm	Sieve 3 d=0.25 mm	Sieve 4 d=0.05 mm	Residue >0.05 mm
1	7.71	15.60	52.05	24.60	0.04
2	8.40	16.36	51.63	23.50	0.12
3	6.89	15.09	52.82	25.09	0.10
4	7.77	16.27	50.03	25.83	0.10
5	6.20	16.15	54.24	23.27	0.14
6	8.03	15.76	50.39	25.75	0.06
7	7.31	15.79	50.93	25.92	0.06
8	7.56	14.72	52.21	25.43	0.08
9	6.54	16.28	52.61	24.50	0.06
10	7.06	14.32	54.66	23.84	0.12
11	7.70	15.63	52.91	23.67	0.10
12	8.05	15.26	52.64	23.99	0.06
Average	7.43	15.60	52.26	24.62	0.09

Table 7 - Percentage of particle size distribution of Type 3 sands

Sample number	Granules percentage, %				
	Sieve 1 d=2 mm	Sieve 2 d=0.5 mm	Sieve 3 d=0.25 mm	Sieve 4 d=0.05 mm	Residue >0.05 mm
1	0.90	35.58	48.29	15.19	0.04
2	0.84	32.99	49.90	16.21	0.06
3	0.64	34.64	51.59	13.08	0.06
4	0.74	35.12	49.87	14.21	0.06
5	0.62	34.56	50.42	14.34	0.06
6	0.52	33.42	50.59	15.43	0.04
7	0.72	32.85	51.33	15.04	0.06
8	0.76	36.15	47.46	15.60	0.04
9	0.84	34.75	49.28	15.09	0.04
10	0.68	35.90	49.36	13.98	0.08
11	0.66	35.51	49.06	14.73	0.04
12	0.76	32.90	51.20	15.08	0.06
Average	0.90	35.58	48.29	15.19	0.04

Table 8 - Percentage of particle size distribution of Type 4 sands

Sample number	Granules percentage, %				
	Sieve 1 d=2 mm	Sieve 2 d=0.5 mm	Sieve 3 d=0.25 mm	Sieve 4 d=0.05 mm	Residue >0.05 mm
1	0.24	42.59	46.71	10.30	0.16
2	0.34	40.10	50.44	9.02	0.10
3	0.42	41.24	48.00	10.20	0.14
4	0.28	43.43	44.85	11.31	0.14
5	0.36	42.24	46.54	10.76	0.10
6	0.28	40.25	47.87	11.50	0.10
7	0.38	44.45	46.03	9.03	0.12
8	0.46	43.24	47.65	8.54	0.10
9	0.30	41.86	48.25	9.49	0.10
10	0.42	43.00	45.98	10.50	0.10
11	0.38	43.57	46.01	9.92	0.12
12	0.32	41.43	49.32	8.83	0.10
Average	0.35	42.28	47.30	9.95	0.11



a – Type 1 b – Type 2

c – Type 3 d – Type 4

Figure 3 - Graphs of granulometric composition of sands

Figures 3a - 3d show the graphs of particle size distribution of the compared sand types. The X-axis shows the values of fraction sizes, and the Y-axis shows their percentages. In this case, the ordinate axis represents the percentage of particles whose fraction sizes are smaller than the corresponding value on the abscissa axis. That is, according to the graph of Figure 3, the fraction size is 7.49%, greater than 0.5 mm, of which 6.93% is less than 2 mm and 0.56% is greater than 2 mm (according to the summary table). It can also be interpreted that those fractions 100-7,49=92,51% with dimensions less than 0,5 mm.

According to the statistical results, all the obtained data have a close relationship with the evaluated indicators. For type 1, the coefficient of variation within the size fractions does not exceed 20%, inaccuracy lies in the range from 1.8 to 19.87 %. For type 2 this value does not exceed 35%, and for dusty fractions, the fractional content of which does not exceed 0.1% by mass of samples. For the rest, the sandy fractions in samples of type 2, the variation does not exceed 9% (from 2.55 to 8.42). A similar pattern is observed for Type 3 samples: the variation of clay particles has an unstable value of 24.45%, and within the sand fractions, the coefficient varies from 2.51 to 14.78%. For type 3, the coefficient of variation within the size fractions, just as in the case of type 1 does not exceed 20%, exactly ranges from 3.36 to 19.19%.

In general, it has been observed that maximum instability of mass ratios of fractions in the boundary ranges. That is, in the extreme ranges of sandy soils (or rather lying outside it) corresponding to the maximum (not more than 2 mm) and minimum (not less than 0.05 mm) allowable fraction for sand. For types 1 and 4, the maximum instability was detected in the range exceeding the maximum allowable value of sand fractions: fractions of size greater than 2 mm. In both cases, the mass fraction of such inclusions in the samples does not exceed 1%, which can be regarded as an error. For sand types 2 and 3, the maximum instability of the results corresponds to the lower limit of the range of sandy soils, and clay inclusions, the total content of which on average does not exceed 0.1% by mass in both cases. This low percentage can also be excluded from the particle size distribution analysis.

To assess the homogeneity of the composition, we can use the classical formula for the degree of heterogeneity of sandy soils:

$$C_c = \frac{D_{60}}{D_{10}}, \quad (1)$$

where C_c is a degree of heterogeneity of soils;

D_{60} is a particle diameter, less than which 60% of grains are in the soil;

D_{10} is a diameter of particles, less than which 10% of grains are in the soil.

The classical homogeneity assessment (Table 9) does not work, because the particle size distribution assessment is performed according to an enlarged scheme. To evaluate the particle size distribution, selected only those sieves that correspond to the boundary sizes of fractions, i.e. their limiting maximum and minimum values. If intermediate sieve values were used, the results would have been more correct, with more appropriate data regarding the estimation of homogeneity by the conditional index Cc. The homogeneity of the sands will be assessed by direct estimation of the percentage of particles of each fraction. Figure 4 shows the values of the percentage of particle content by fractions. The graph shows that most of the fractions of all four compared types of sands have a size range of 0.5-0.25 mm (not inclusive), with the maximum value of the percentage of such particle size observed in the samples of Type 1. The dependence that has developed to estimate the soil homogeneity of this particular case:

$$C_c = \left(1 - \frac{100 - x_{max}}{100 - x_{max-1}}\right) x100 \quad (2)$$

where, C_c - degree of heterogeneity;

x_{max} - percentage ratio corresponding to the maximum distribution of particles by mass;

x_{max-1} - percentage ratio corresponding to the second maximum particle mass distribution.

Table 9 – Degree of homogeneity of sands

Sample number	Sand type	Degree of homogeneity	Homogeneity criterion
1	Type 1	Cc = 0,5/0.05=10	<3 heterogeneous
2	Type 2	Cc = 0,5/0.05=10	<3 heterogeneous
3	Type 3	Cc = 0,5/0.05=10	<3 heterogeneous
4	Type 4	Cc = 2/0.05=10	<3 heterogeneous

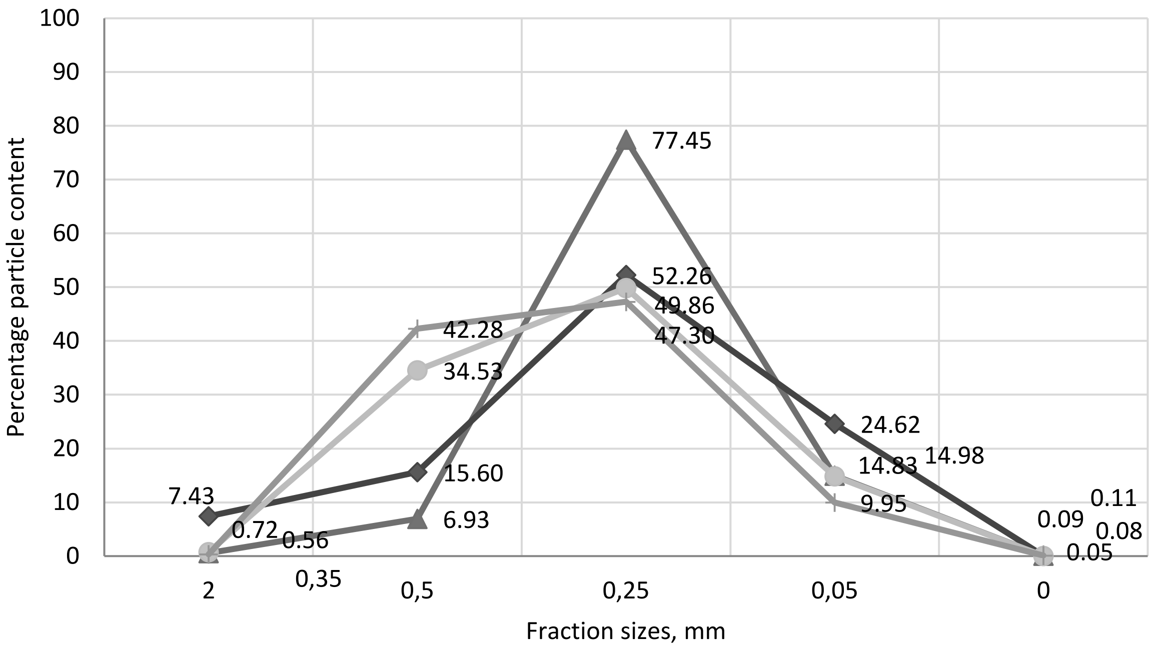


Figure 4 - Percentage distribution of fractions by weight

Table 10 – Evaluation of sand homogeneity

Type	Max	Max-1	Cc
Type 1	77.45	14.98	73.5
Type 2	52.26	24.62	36.7
Type 3	49.86	34.53	23.4
Type 4	47.30	42.28	8.7

This dependence takes into account the following evaluation conditions: the percentage of the maximum fraction relative to the total mass of the sample, as well as the criterion of relativity of the maximum fractions to the fractions immediately following the maximum value (by mass). Thus, an assessment of homogeneity is given both relative to the total mass of the sample and relative to the available difference between the percentage distribution. For a comparative (not absolute) assessment, it is sufficient to compare the percentage ratio of the maximum value of the particle mass distribution to the second value of the maximum particle distribution. The degree of heterogeneity ranges from 0 to 100%, and the interpretation of the result is summarized as follows: the larger the value of the degree, the greater the homogeneity of the sand. The results of the calculations are presented in Table 10.

According to the results, type 1 sand has maximum homogeneity and type 4 sand has minimum homogeneity. In general, the results of the heterogeneity assessment are quite logical: Type 1 has the maximum distribution index, and the difference with the second value of the mass distribution is also maximum; Types 2 and 3 have a relatively similar pattern to Type 1, but both of these indicators are inferior to Type 1; Type 4 has the lowest distribution values with the minimum difference between the maximum and second after the maximum mass distribution of fractions.

From the point of view of the suitability of sand about the prevailing size of fractions, the most preferable is the sand Type 1 deposit of building sands Eltok, located in the Arshalyn district of Akmola region near the village of Volgodonovka, 44 km southeast of Astana. This type of sand has the highest percentage of the smallest fractions, relative to other comparable types of sand. For the production of foam concrete, the grain size index is important, the smaller the size of sand fractions, the more structured the final product will be, with a more stable pore structure.

Figure 5, table 11 shows the results of weighing sand samples of 1000 grams in the dry state (after drying to constant weight) and in water-saturated state.

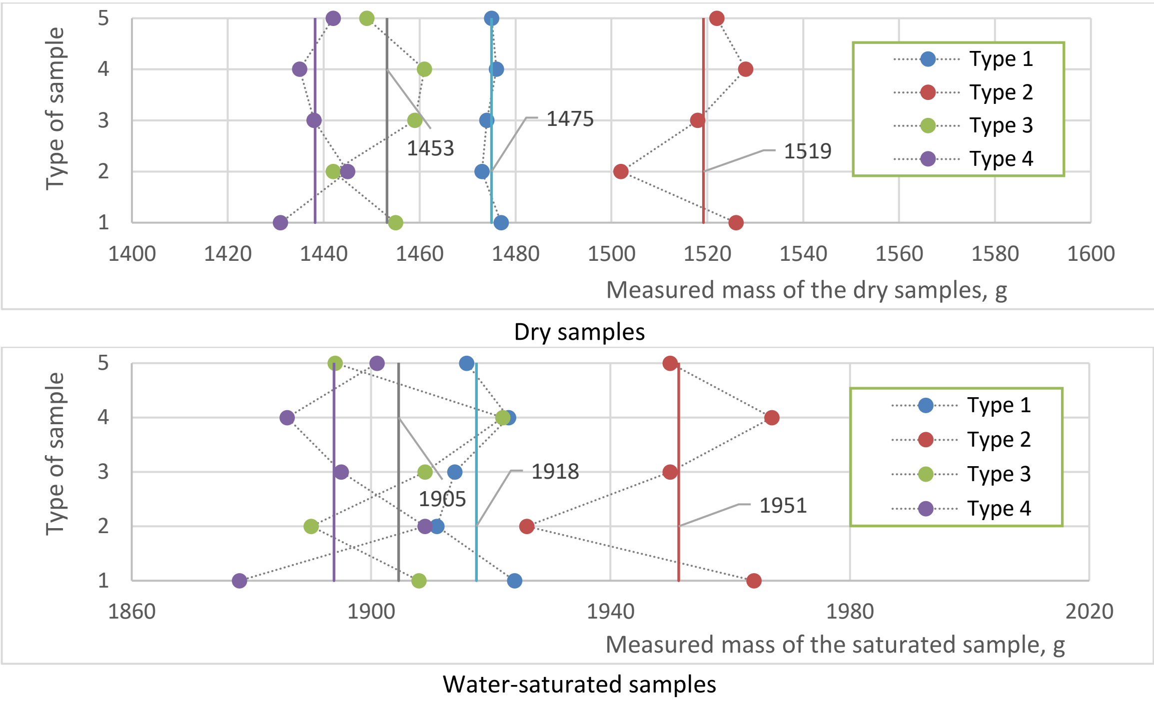


Figure 5 – Weighing results of sand samples

Table 11 – Results of density and moisture estimation of sands

Sand type	Dry sand density pd, g/cm²	Wet sand density, pw, g/cm²	Sand particle density, ps, g/cm²	Natural density of sand, pn, g/cm²	Natural humidity, vn, %	Moisture at full water saturation, vw, %
Type 1	1.475	1.918	2.648	1.615	9.5	79.5
Type 2	1.519	1.951	2.674	1.634	7.6	76.1
Type 3	1.453	1.904	2.647	1.579	8.7	82.1
Type 4	1.438	1.894	2.643	1.542	7.2	83.8

Table 12 – Results of sand shrinkage evaluation

Sand type	Dry sand volume, ml	Soaked sand volume, ml	Shrinkage volume, ml	Relative shrinkage, %	Quadratic deviation	Variation coefficient, %
Type 1	160	138	22	13.75	1.7	1.231884
Type 2	160	135	25	15.63	1.9	1.407407
Type 3	160	142	18	11.25	1.5	1.056338
Type 4	160	141	19	11.88	1.8	1.276596

In the graphs, each point corresponds to a private value of density, and the values of the central lines correspond to the average values of each of the compared types of sand. The results of density determination are shown in Table 11. The table also shows the results of calculations of the natural moisture content of sands and their moisture content after their complete water saturation.

According to the test results, the maximum density in the natural state is in type 2 sands and minimum in type 4 sands, and in both cases, the natural moisture content is a minimum of 7.6 and 7.2 % respectively. The maximum natural moisture content is observed in type 1 samples. Maximum density in dry conditions and water-saturated conditions was found in type 2 sands and minimum of both densities in type 4. A similar pattern was found when comparing the densities of soil particles, with the only difference being that the results of densities of all the types compared are closer. The percentage of the difference between the maximum and minimum values in the case of dry soil density is +/- 5% and in the case of particle density +/- 5%.

The obtained private density values have a high degree of convergence because the coefficients of variation have very low values: for sands of type 1 are 0.1-0.3%; for sands of type 2 are 0.7-0.8%; for sands of type 3 are 0.5-0.7%; for sands of type 4 are 0.4-0.6% (variation of private density values of dry and wet sands, respectively). The low variation indices testify to the qualitative quartering performed before the tests, as well as to the high approximation of the obtained results to the average statistical values.

Table 12 shows the results of the shrinkage of samples after soaking. According to the test results, the maximum shrinkage was found in type 1 samples and the minimum shrinkage in type 3 and 4 samples. The test results can be decisive in the choice of sand for the production of foam concrete with other equal evaluation indicators. According to the analysis of statistical indicators, we also conclude that there is a sufficiently close relationship between the individual values among themselves, hence, the high reliability of the obtained averages.

Conclusion

Based on the results of the tests performed, the following generalized conclusions can be drawn:

1. The physical characteristics of sands vary from one type to another, indicating differences in their natural composition and properties.

2. The maximum density in the natural state is observed in type 2 sands while the minimum density is observed in type 4 sands. Both types of sands are characterized by low levels of natural moisture content of 7.6% and 7.2% respectively.

3. Maximum density in dry and water-saturated conditions is also found in type 2 sands while minimum density in both the states is found in type 4 sands.

4. As a result of shrinkage tests of the specimens, maximum shrinkage is found in type 1 sands while minimum shrinkage is observed in type 3 and 4 specimens.

5. From the point of view of sand suitability for the production of foam concrete, the most preferable is Type 1 sand from the construction sand deposit Eltok, located in Arshalyn district of Akmola region near Volgodonovka village, 44 km southeast of Astana. This type of sand has the highest content of the smallest fractions compared to other types of sand. For foam concrete production, the size of fractions is important, and the smaller it is, the more structured the final product will be with a more stable pore structure.

Conflict of interest. The corresponding author declares that there is no conflict of interest.

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Екі сатылы көбік енгізу әдісімен көбікбетон өндіруге арналған құмның физикалық-механикалық сипаттамаларын бағалау

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ТҮЙІНДЕМЕ
Мақалада көбік бетон өндірісінде қолдануға жарамдылығын бағалау мақсатында карьер құмының қасиеттеріне жүргізілген тәжірибелік зерттеулердің нәтижелері берілген. Ақмола облысы аумағындағы карьерлік құмды өндіру аймақтары талданып, олардың физика-механикалық көрсеткіштері бойынша сипаттамалары келтірілген. Құмның физика-механикалық сипаттамалары құмның төрт түрі бойынша бағаланды. Негізгі бағалау параметрлері: гранулометриялық құрамы, біркелкілігі, шөгуі, тығыздығы және құмның ылғалдылығы болды. Зерттеу нәтижелері бойынша құмдардың физикалық сипаттамалары олардың түріне байланысты өзгеретінін көрсетті, бұл осы материалдардың табиғи құрамы мен қасиеттерінде айырмашылық бар екендігін дәлелдейді. Әртүрлі типтегі құмдардың біртектілігін бағалау, түрлер арасындағы елеулі айырмашылықтарды растайды. Ең жоғары біртектілік (x_{max}=77,45; x_{max-1}=14,98; Cc=73,5%) 1-типті құмда байқалса, 4-типті құмда біртектіліктің минималды дәрежесі (x_{max}=47,30; x_{max-1}= 42,28; Cc=8,7%) байқалады. Сынақ нәтижелеріне сәйкес 2-типті құмда екі тығыздықтың да максималды мәндері: ρ_d = 1,519 г/см^2, ρ_w = 1,951 г/см^2, ал 4-тип үшін екі тығыздықтың ең төменгі мәндері: ρ_d = 1,438 г/см^2, ρ_w = 1,894 г/см^2 болады. 1-типті үлгілер үшін максималды табиғи ылғалдылық v_n=9,5%, ал ең төменгі мәндері 7,6% және 7,2% (2- және 4-типтер). Алынған жартылай тығыздық мәндері конвергенцияның жоғары дәрежесіне ие, өйткені вариация коэффициенттері өте төмен: 1-типті құмдар үшін олар 0,1-0,3% құрайды; 2-типті құмдар үшін олар 0,7-0,8%; 3-типті құмдар үшін олар 0,5-0,7%; 4-типті құмдар үшін 0,4-0,6% құрайды (сәйкесінше құрғақ және дымқыл құмның нақты тығыздықтары өзгереді). Сынамалардың шөгуі бойынша сынау нәтижелерін талдау көрсеткендей, ең жоғары шөгу 1-типті құмдарда 15,63% тең, ал ең аз шөгу 3- және 4-типті үлгілерге тән (11,25% және 11,88%). Көбік бетон өндірісіне құмның жарамдылығын ескере отырып, Елтоқ құрылыс құм кен орнында өндірілген 1-типті құм ең қолайлы болып табылады.

Түйін сөздер: құм, көбікбетон, физика-механикалық сипаттамалар, шөгу, түйіршіктік құрамы, біртектілік дәрежесі.

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Оценка физико-механических характеристик песка для производства пенобетона методом двухстадийного введения пены

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АННОТАЦИЯ
В статье представлены результаты экспериментальных исследований свойств карьерного песка с целью оценки их пригодности для использования в производстве пенобетона. Проанализированы участки добычи карьерного песка на территории Акмолинской области и дана их характеристика на физико-механические показатели. Оценка физико-механических характеристик песка произведена для четырех типов песка. Основными оценочными параметрами, являлись: гранулометрический состав, однородность, усадка, плотность и влажность песков. Результаты исследования показали, что физические характеристики песков варьируются в зависимости от их типа, что свидетельствует о различиях в природном составе и свойствах этих материалов. Оценка однородности песков различных типов подтверждают значительные различия между типами. Наибольшая однородность (x_{max}=77,45; x_{max-1}=14,98; Cc=73,5%) отмечена у песка типа 1, тогда как песок

типа 4 демонстрирует минимальную степень однородности (x_{max}=47,30; x_{max-1}=42,28; Cc=8,7%). Согласно результатам испытаний, максимальные показатели обоих плотностей у типа 2 составляет: ρ_d =1,519 г/см^2, ρ_w=1,951 г/см^2, а минимальные показатели обоих плотностей у типа 4 составляет: ρ_d=1,438 г/см^2, ρ_w=1.894 г/см2. Максимальная естественная влажность у образцов типа 1 - v_n=9,5%, тогда как минимальные значения 7,6% и 7,2% (Тип 2 и 4). Полученные частные значения плотности имеют высокую степень сходимости, поскольку коэффициенты вариации имеют очень низкие показатели: для песков типа 1 составляют 0,1-0,3%; для песков типа 2 составляют 0,7-0,8%; для песков типа 3 составляют 0,5-0,7%; для песков типа 4 составляют 0,4-0,6% (вариации частных значений плотности сухого и мокрого песков соответственно). Анализ результатов испытаний по усадке образцов показал, что максимальная усадка наблюдается у песков типа 1 равная 15,63%, в то время как минимальная усадка характерна для образцов типа 3 и 4 (11,25% и 11,88%). С учетом пригодности песка для производства пенобетона, наиболее предпочтительным является песок Типа 1, добываемый в месторождении строительных песков Ельток.

Ключевые слова: песок, пенобетон, физико-механические характеристики, усадка, гранулометрический состав, степень однородности.

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