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Integration of Thermal Power Plant Ash and Slag Waste into the Production of Aerated Concrete

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Developing compositions and technologies for concrete production typically requires a complete cycle of activities—from theoretical modelling and laboratory trials to semi-industrial and industrial testing, followed by pilot-scale manufacturing. When the goal is to achieve specific target properties, discrepancies between laboratory and industrial outcomes are often observed due to differences in curing regimes, scale, and material variability. To address this, the present study proposes a method for introducing correction factors that allow laboratory data to be translated into reliable industrial performance indicators. Transition coefficients for operational quality control of non-autoclaved aerated concrete on ash and slag waste have been developed. It has been established that to predict the actual strength of industrial samples based on the results of tests in 1 day with heat treatment, a coefficient of 1.684 is used, and for density, 0.851. When using the results of tests in 7 days without heat treatment, these coefficients are 1.917 for strength and 0.838 for density, respectively. These coefficients allow for minimising time and resources during the transition to industrial production.

1. Introduction

Cellular concrete remains a widely used material in the construction industry, both in monolithic structures and prefabricated units, owing to its unique combination of properties that distinguish it from traditional dense concrete and ceramic bricks (Kouddane et al., 2022). Its high thermal and acoustic insulation capacity, lightweight nature, fire resistance, and durability make cellular concrete particularly suitable for use in seismic-prone regions. However, these advantages are counterbalanced by the material's high sensitivity to variations in raw material composition and production conditions. Achieving the required strength and density characteristics depends on a complex interplay of multiple parameters including raw material types, component ratios, water-to-solid ratio (W/S), type and dosage of pore-forming agents, and curing regimes. Standardized classification of cellular concrete primarily involves average density (D-class) and compressive strength (B-class). Recent studies have explored new methods of modifying cellular concrete using industrial waste and advanced additives. While they achieved notable increases in compressive (by 54 %) and flexural strength (by 45 %), the study lacked control over density—a critical parameter for ensuring structural and thermal efficiency in lightweight concretes.

Non-autoclaved aerated concrete (NAAC) typically forms a closed-pore structure within the cement matrix and is cured either under ambient conditions or with controlled electric heating. Investigations by Peng et al. (2024) into the role of various constituents—such as NaOH, aluminium powder, and calcium stearate—in sulphoaluminate-based NAAC revealed significant effects on compressive strength and density, though density was often measured only at the final age, without intermediate tracking. Given the unique pore structure and formation mechanisms of aerated concrete, the methodologies for mix design and property assessment differ significantly from those applied to conventional concrete. Samuylov et al. (2019) proposed several procedures for NAAC mix optimization, particularly focusing on water-to-solid ratios and binder-to-silica balances. However,

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a unified and validated approach for predicting both strength and density—especially in slag-containing aerated concrete—has yet to be established. Several studies have incorporated industrial waste materials such as fly ash, blast furnace slag, and rice husk ash to enhance mechanical performance. For instance, Rudenko et al. (2025) reported that ash and slag waste rich in SiO_2, Al_2O_3, Fe_2O_3, and CaO (~31.5 wt %) improved the strength of NAAC to 2.35 MPa. Yet, a systematic approach to analyzing density dynamics over different curing periods remains underexplored. This study is a continuation of the previous work by Sadenova et al. (2024) and aims to fill this gap by developing a methodology for predicting the main properties, in particular compressive strength and density, of cellular concrete based on ash and slag waste. Particular attention is paid to establishing conversion factors between laboratory and industrial test results, which provides a basis for more accurate design and production of lightweight concrete using recycled materials.

2. Materials and Experimental Design

The object of research was non-autoclaved aerated concrete blocks based on ash and slag waste from Boiler Room No. 2 of the Ust-Kamenogorsk Thermal Power Plant. The raw mix included CEM I 42.5H cement as a binder, aluminum powder suspension (PAP-1 grade) as a gas-forming agent, and caustic soda as a stabiliser. Drinking water was used for mixing. The experimental study was carried out in two stages:

- Stage 1: Laboratory experiments to observe the strength and density development of 15×15×15 cm cube samples at early curing stages (both under natural and heat-treated conditions). Series 1 samples were steam-cured at 90 °C for 6 h, then half were tested after 1 d, and the rest stored under normal conditions until d 28. Series 2 samples were cured under normal conditions and tested at 7 d and 28 d.
- Stage 2: Comparative analysis of samples made in laboratory versus industrial conditions. Identical formulations and raw materials were used for all batches. The experimental setup is shown in Figure 1.

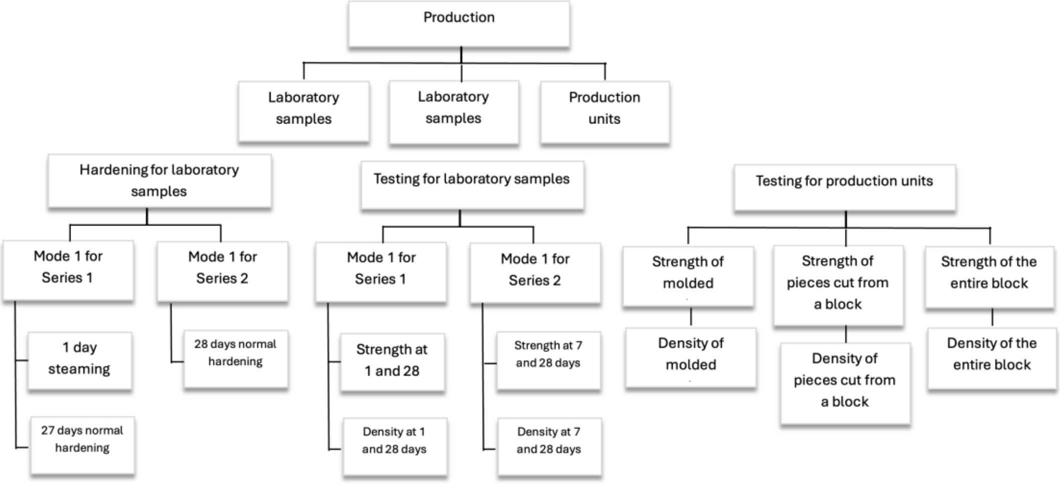

Figure 1: Schematic diagram of the experiment

In the course of the second stage research, a parallel experiment was carried out on samples of aerated concrete produced in laboratory conditions and samples produced at the production site. In this paper, the experiment was conducted on four batches of laboratory mixes and four batches of factory-made blocks, from which cube samples were sawed and the blocks were tested. In laboratory conditions, the samples were made in standard moulds of size 150x150x150 mm. After 24 h the specimens were demolded and placed in a normal curing chamber for further strength gain. Industrial samples were produced at the plant for the production of aerated concrete blocks "Tekhnostroy" LLP. The researches were carried out on samples-blocks with nominal dimensions 600x200x199 mm. The blocks are made in moulds of 12 pieces. After completion of lifting the aerated concrete is sawed into blocks using string saws and placed in the chamber for strength gain. During the experiment, the strength and density of the aerated concrete was determined. For the test, 2, 4, 6, 8 and 12 blocks were taken from the mould. Since the blocks made of aerated concrete of non-autoclaved curing have heterogeneity in their structure (pores adjacent to the edges are wrinkled and have a denser structure than inside the block), therefore the tests were carried out according to two schemes. One part of the blocks was tested according to the norms for aerated concrete blocks, the other part according to the norms for concrete wall stones. When tested according to the norms for porous concrete from the middle of the block sawed out standard specimens of size 150x150x150 mm, which were then tested. When testing according to the method for concrete wall stones, whole blocks of aerated ash concrete were tested. Strength tests were carried out on an electrohydraulic testing press PI-100-I-A-D-1-2 with a measuring range of 0-10 t. The density was determined using an MG4B moisture meter. According to the average values of changes in strength and density, the coefficients in the first and second stage were determined. Then the coefficient of transition from the strength and density of aerated concrete samples at the time control point to the strength and density of industrial samples was determined. The coefficients of the first stage were determined as a partial of the result at the design age (28 d), and the coefficients of the second stage were determined as a partial of the test results of the industrial specimens. The final transient coefficient was obtained by multiplying the coefficients of the first and second stages.

3. Results and discussion

The mechanical properties (compressive strength and density) of the first series of non-autoclaved aerated concrete samples tested under controlled laboratory conditions are presented in Table 1.

Table 1: Test results of the first series of samples

Batch number	Strength after thermal treatment, MPa	Strength at the age of 28 d, MPa	Density after thermal treatment, kg/m^3	Density at the age of 28 d, kg/m^3	Strength increase, MPa	Strength increase, %	Density reduction, kg/m^3	Density reduction, %
1	1.48	2.30	832.68	737.64	0.82	35.60	95.04	12.88
2	1.46	2.33	827.28	747.36	0.87	37.23	79.92	10.69
3	1.64	2.53	833.76	756.00	0.88	35.00	77.76	10.29
4	1.82	2.69	847.80	768.96	0.87	32.23	78.84	10.25
5	1.88	2.85	844.56	744.60	0.97	33.97	99.96	13.42
6	1.79	2.89	842.52	755.82	1.10	38.21	86.70	11.47
7	1.93	2.96	833.34	762.96	1.04	34.94	70.38	9.22
8	1.56	2.25	851.70	773.16	0.69	30.52	78.54	10.16
9	1.53	2.42	873.12	793.22	0.89	36.72	79.90	10.07
10	1.60	2.44	889.44	812.26	0.84	34.38	77.18	9.50
11	1.55	2.49	896.58	821.10	0.93	37.55	75.48	9.19
12	1.79	2.56	922.08	828.24	0.77	30.04	93.84	11.33
13	1.76	2.59	921.06	836.40	0.83	32.07	84.66	10.12
14	1.75	2.69	916.98	834.36	0.94	35.00	82.62	9.90
15	1.76	2.71	920.04	831.30	0.95	35.07	88.74	10.67
Average	1.69	2.58	870.20	786.89	0.89	34.51	83.30	10.61

These results serve as the initial ones for further comparison with samples of pilot and industrial scale. The values of compressive strength and density of 15 batches of samples are shown when tested after heat treatment and after 28 days. The table also shows the calculated values of strength increase and density decrease of the samples, as well as their percentages. It is evident that in all batches of aerated ash concrete, there is an increase in strength and a decrease in density at the design age of 28 days compared to the strength in the control period of 1 day. For a visual analysis of the change in the dynamics of strength and density, a histogram of strength increase and a histogram of density change are plotted in Figure 2.

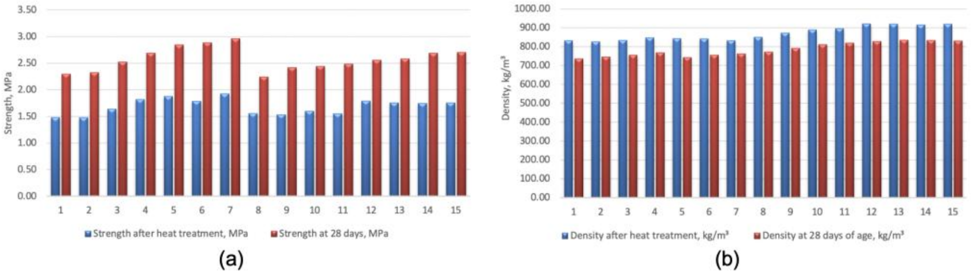

Figure 2: (a) Compressive strength of samples after heat treatment and at 28 d of curing; (b) Density of samples after heat treatment and at 28 d of curing.

The analysis of the obtained results showed that in the samples, which were subjected to heat treatment, the strength at the design age in comparison with the strength immediately after steaming (at the age of 1 d) increased on average by 34.51 %. The minimum strength increase was 30.04 %, compressive strength changed from 1.79 to 3.04 MPa. The maximum increase in strength was 37.55 %, i.e. from 1.55 to 2.49 MPa. At the same time there was a decrease in density. The decrease in density in the samples after 28 d as compared to the samples after steaming averaged 10.61 %. The minimum density reduction was 9.19 % and ranged from 896.58 to 821.10 kg/cm$^{3.}$ The maximum density reduction was 12.88 % and ranged from 832.68 to 737.64 kg/cm^3 giving a change in density class from D850 to D750. The results of testing the samples of the second series in laboratory conditions are given in Table 2. Table 2 shows the compressive strength and density values of 15 batches of specimens when tested after curing for 7 and 28 d. The table also shows the calculated values of increase in strength and decrease in density of the specimens, as well as their percentages. This table shows that in all batches of the second series of aerated ash concrete, there is an increase in strength and a decrease in density at the design age of 28 d compared to the strength at the control period of 7 d. For a visual analysis of the dynamics of changes in strength and density, a histogram of strength increase and a histogram of density change are plotted in Figure 3.

Table 2: Test results of the second series of specimens

Batch number	Strength after heat treatment, MPa	Strength at the age of 28 d, MPa	Density after heat treatment, kg/m^3	Density at the age of 28 d, kg/m^3	Strength increase, MPa	Strength increase, %	Density reduction, kg/m^3	Density reduction, %
1	1.58	2.52	733.43	617.50	0.95	37.36	115.93	18.77
2	1.23	2.12	761.74	646.00	0.90	42.27	115.74	17.92
3	1.41	2.37	932.90	798.95	0.96	40.56	133.95	16.77
4	1.12	2.16	827.07	668.80	1.04	48.02	158.27	23.67
5	1.47	2.35	853.45	689.70	0.87	37.25	163.75	23.74
6	1.45	2.75	996.64	811.30	1.30	47.14	185.34	22.85
7	1.67	2.74	950.00	807.50	1.07	39.00	142.50	17.65
8	1.84	2.93	897.50	739.10	1.09	37.31	158.40	21.43
9	1.68	3.31	945.17	797.05	1.63	49.19	148.12	18.58
10	1.96	3.34	935.75	760.95	1.38	41.35	174.80	22.97
11	1.93	3.49	933.10	773.30	1.56	44.69	159.80	20.66
12	1.65	3.12	977.00	817.48	1.47	47.23	159.52	19.51
13	1.79	3.23	939.55	818.90	1.44	44.73	120.65	14.73
14	1.93	3.34	951.90	820.80	1.42	42.40	131.10	15.97
15	2.07	3.31	946.20	812.25	1.25	37.69	133.95	16.49
Average	1.65	2.87	905.43	758.64	1.22	42.42	146.79	19.45

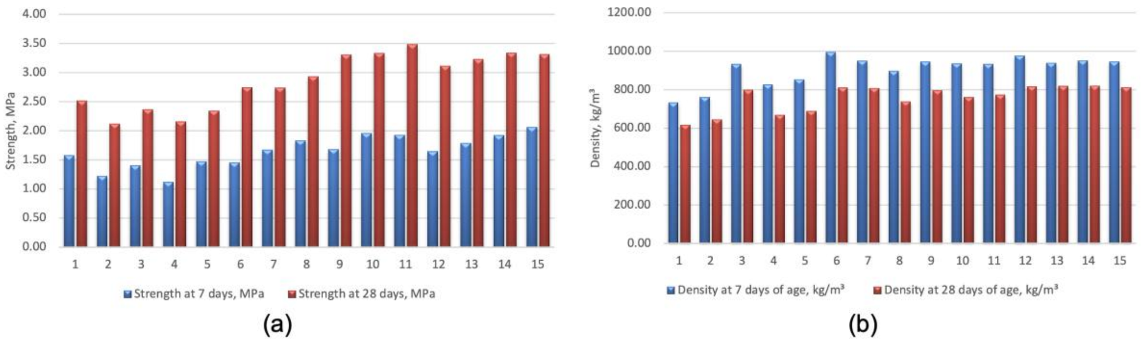

Figure 3: (a) Compressive strength of samples at 7 d and 28 d of curing; (b) Density of samples at 7 d and 28 d of curing.

The analysis of the obtained results showed that in the specimens that gained strength in natural conditions, the strength at the design age compared to the strength at the age of 7 d increased on average by 42.42 %. The minimum strength increase was 37.25 % (from 1.47 to 2.35 MPa) and the maximum was 49.19 % (from 1.68 to 3.31 MPa). A decrease in density was also observed in the samples gaining strength in vivo. The density reduction in the samples after 28 d compared to the samples at the age of 7 d averaged 19.45 %. The minimum density reduction was 14.73 % - from 939.55 to 818.90 kg/cm^3, which corresponds to a change in the density class of aerated ash concrete from D950 to D850. The maximum density reduction is 23.74 % from 853.45 to 689.70 kg/cm^3, i.e. from D900 to D700. Results of strength and density tests are presented in Table 3.

Table 3: Comparative strength and density test results

Batch number	Strength of laboratory samples, MPa	Strength of specimens cut from blocks, MPa	Strength of blocks, MPa	Density of laboratory samples, kg/m^3	Density of samples sawn from blocks, kg/m^3	Density of blocks, kg/m^3
Batch 1	2.32	2.14	1.58	794	754	810
Batch 2	2.50	2.18	1.44	804	751	820
Batch 3	2.29	2.11	1.55	766	713	810
Batch 4	2.37	2.16	1.70	802	756	816
Batch 5	2.43	2.21	1.71	810	766	827
Average value	2.38	2.16	1.60	795	748	816

Table 3 shows the values of compressive strength and density of 5 batches of samples produced in laboratory and industrial conditions. The results of tests of industrial samples according to two standard methods are shown - by cutting cubes out of the block and testing of the whole block. This table shows that in all the batches, the strength of laboratory specimens is higher than the strength of industrial specimens. The strength of whole blocks tested is the lowest. The lowest density is observed for the specimens sawn from industrial specimens and the highest for whole blocks. For visual analysis of changes in the dynamics of strength and density, a histogram of strength changes and a histogram of density changes are plotted in Figure 4.

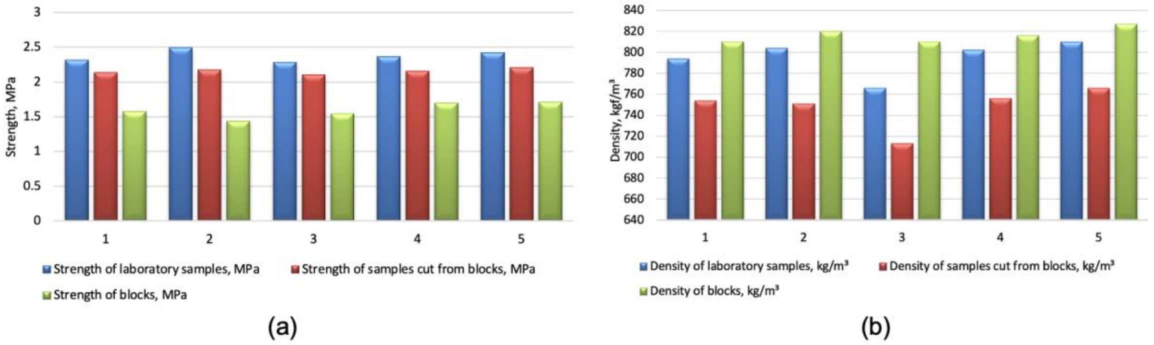

Figure 4: (a) Variation in compressive strength between laboratory samples, samples cut from blocks, and full blocks; (b) Variation in density between laboratory samples, samples cut from blocks, and full blocks.

In this work, the results of testing of whole blocks are taken as reference (final) values. The strength of the laboratory specimens is 48.7 % and the strength of the specimens sawn from the blocks is 35 % higher compared to the strength of the whole blocks. The density of the laboratory specimens is 2.6 % and the density of the specimens sawn from the blocks is 8.3 % less compared to the strength of the whole blocks. Therefore, when selecting the composition of aerated concrete, it is necessary to introduce a correction factor for the transition to the strength of factory-made blocks. Determination of the coefficient of transition from the strength and density of samples in the control point, to the strength and density of industrial samples is shown in Table 4.

Table 4: Determination of the transition coefficient

Transition coefficient	Strength	Density
Transition coefficient from samples after heat treatment to samples aged 28 d	1.740	0.838
Transition coefficient from 28-d-old samples to industrial samples	1.102	0.941
Final conversion factor from samples after heat treatment to industrial samples	1.917	0.789
Transition coefficient from samples aged 7 d to samples aged 28 d	1.528	0.904
Transition coefficient from 28-d-old samples to industrial samples	1.102	0.941
Total transition factor from 7-d-old samples to industrial samples	1.684	0.851

Analysis of the experimental results showed that the density and strength of aerated concrete in the samples made in laboratory conditions, as well as pilot production samples tested according to different standardised methods have differences. The maximum values of density and minimum values of strength were shown by the samples tested as whole blocks. The conversion from the strength and density of aerated concrete samples at the time control point to the strength and density of industrial samples using the coefficients is shown in Figure 5.

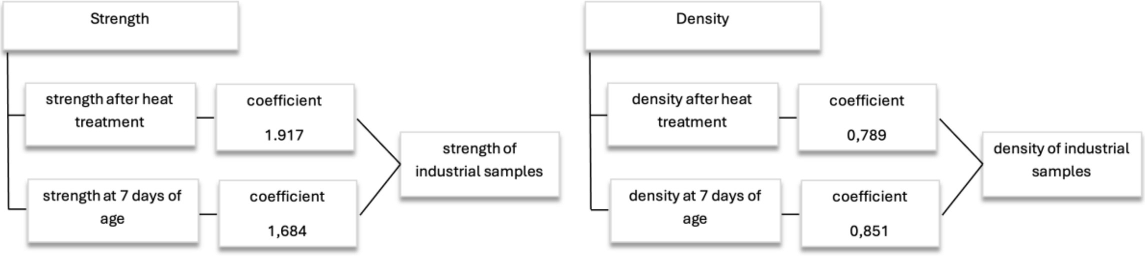

Figure 5: Determination of strength and density of industrial samples.

4. Conclusions

The conducted research demonstrated that both the compressive strength and density of non-autoclaved aerated concrete are significantly affected by curing duration and initial storage conditions. A clear distinction was observed between the properties of samples tested under laboratory and industrial conditions. To reduce the time required for optimizing the mix design, a predictive approach using transition coefficients was proposed and validated. The experimental data confirmed that early-age laboratory results, particularly at 1 and 7 d, can be used to estimate the final performance of industrially produced blocks. Coefficients for translating strength and density from laboratory-scale to industrial-scale conditions were derived, taking, into account both heat-treated and naturally cured scenarios. These findings enable more efficient planning and composition selection in industrial practice. Given the structural relevance of full-size blocks, it is recommended to use their mechanical properties as reference values in accordance with the "worst-case scenario" principle. The proposed methodology offers practical utility for engineers and researchers working on the implementation of ash and slag waste in the industrial production of aerated concrete. A promising task for further research may be to test the applicability of the proposed method to an expanded raw material base (for example, different types of ash and slag materials) and the additives used.

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