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Optimizing sodium sulfonate dosage in non-autoclaved aerated concrete: effects on pore stability, strength, and abrasion resistance

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Abstract. This study evaluates sodium sulfonate as a structuring surfactant for non-autoclaved aerated concrete to stabilize pore formation and improve performance. A laboratory dosage series (0-0.25% by cement mass, water-to-cement ratio 0.45) and a pilot D700 production verification (GB1-GB4) were performed. At 28 days, the reference mixture reached 1.5-2.0 MPa, while 0.10-0.15% sodium sulfonate increased strength to 2.3-2.7 MPa; higher dosages reduced strength and impaired pore stability. In the pilot series, average density ranged from 610 to 740 kg/m^3 and compressive strength from 2.0 to 2.5 MPa, with GB3 showing the best strength-to-density balance (SQC 0.034). Abrasion improved from 0.84 to 0.71 g/cm^2. The additive improved plasticity and pore uniformity. Overall, 0.10-0.15% is recommended for practical production with minimal process complexity.
Keywords: aerated concrete, sodium sulfonate, non-autoclave hardening, aluminum powder, cellular structure.

1. Introduction

Among the various types of cellular concrete, special attention is paid to non-autoclaved aerated concrete, the production of which does not require expensive autoclave equipment and high-temperature processing. This approach significantly reduces capital costs and simplifies the technological process, making it accessible to a wide range of construction companies [1].

Cellular concrete is currently one of the most sought-after building materials due to its combination of low specific weight, high thermal and sound insulation properties, and sufficient mechanical strength for use in load-bearing and enclosing structures [2]. These materials are characterized by a porous structure, which is formed by introducing a gas generator into the cement-mineral matrix, significantly reducing density and improving thermal insulation characteristics. One of the key technological challenges in the production of non-autoclaved aerated concrete is the stabilization of the gas structure during the hardening period. The pores formed during the chemical decomposition of the gas generator must be evenly distributed and stable until the cement stone has completely set. Failure to comply with this condition leads to the formation of uneven porosity, a decrease in strength, and a deterioration in the thermal insulation characteristics of the material.

To solve this problem, surfactants are often added to the non-autoclaved aerated concrete formula to help stabilize the foam and form a uniform porous structure. Among them, sodium sulfonate (Na-SO_3 compounds) is of particular importance – an anionic surfactant with the unique ability to simultaneously stabilize gas bubbles, improve the distribution of liquid in cement paste, and regulate the size and shape of pores [3]. In addition, sodium sulfonate performs several additional functions in the concrete mix. It can act as a plasticizer, improving the workability and mobility of the fresh mix without increasing the water-cement ratio, as well as a pore structure regulator, allowing a uniform and fine-pored matrix to be obtained. The introduction of such an additive has a positive effect on strength characteristics, reduces shrinkage deformation, and improves the frost resistance of the finished material. Practical interest in sodium sulfonate is also due to its economic affordability and technological simplicity of application. Experimental studies show that the optimal dosage of this additive depends on the designed density of aerated concrete and can vary between 0.05 and 0.25% of the cement mass, ensuring a balance between strength, density, and stability of the porous structure. In general, the use of sodium sulfonate allows for the production of non-autoclaved aerated concrete with improved performance characteristics that can compete with materials produced using autoclave treatment.

In modern construction, special attention is paid to expanding the raw material base through the use of affordable mineral components and technological additives, such as cements of various compositions, slag products, aluminum powder, and surface-active substances. These materials make it possible to create lightweight, thermally efficient, and durable building products, in particular non-autoclaved aerated concrete, without the use of complex and expensive autoclave equipment [4]. One of the main technological challenges in the production of non-autoclaved aerated concrete is the formation of a stable porous structure. The gas bubbles formed during the reaction of the gas generator with the cement paste must retain their shape and be evenly distributed until the cement stone sets. Failure to comply with this condition leads to uneven porosity, reduced strength, and deterioration of the material's thermal insulation characteristics. Surface-active additives are widely used to stabilize the gas structure. The most promising of these is sodium sulfonate, which simultaneously acts as a foam stabilizer, pore structure regulator, and plasticizer. Its introduction ensures a more uniform distribution of pores, reduces the tendency of the mixture to delaminate, and improves the fluidity of the cement paste. Experiments show that the optimal concentration of sodium sulfonate is 0.05–0.25% of the cement mass, which allows a balance to be achieved between the strength and density of the material.

Previous studies [5] have shown that the addition of sodium sulfonate increases the compressive strength of aerated concrete by 10-20% compared to control samples without additives and simultaneously reduces its density by 5-15%. In addition, stabilizing the porous structure reduces the thermal conductivity of the material to 0.11-0.13 W/m×K, which makes the products more energy efficient and helps reduce the cost of heating and air conditioning buildings. The relevance of developing technologies for the production of non-autoclaved aerated concrete with modifying additives is determined by the need to improve the energy efficiency of buildings and structures. The use of sodium sulfonate allows for the production of lightweight blocks with a uniform porous structure, low thermal conductivity, and satisfactory strength, while reducing energy consumption for technological processes and minimizing operating costs.

This study aims to obtain a non-autoclaved aerated concrete with the addition of sodium sulfonate, providing an optimal combination of strength, density, and thermal insulation properties. The results obtained contribute to the expansion of the raw material base and improve the environmental and economic efficiency of construction technologies [6].

2. Methods

2.1 Materials and experimental design

Non-autoclaved aerated concrete was produced using Portland cement M400 from Caspian Cement, LLP (Aktau, Kazakhstan) as the binder and sodium sulfonate from Damu-Chemistry, LLP (Karaganda, Kazakhstan) as a structuring additive. Quartz sand with a particle size of ≤ 2.5 mm was used as the fine aggregate. The water-to-cement ratio (W/C) was kept constant at 0.45 for the laboratory dosage study. For each composition, at least three specimens were prepared for compressive strength testing and three specimens for abrasion resistance testing. The tests were carried out in the “Building Materials and Building Thermophysics” testing laboratory of the West Kazakhstan Innovation and Technology University (Uralsk, Kazakhstan).

The study consisted of two stages:

- Stage A (laboratory dosage study): sodium sulfonate dosage varied from 0 to 0.25% by cement mass, while cement and sand quantities and W/C were kept constant (Table 1).
- Stage B (pilot/production verification, designed density D700): a plant-scale series (GB1-GB4) produced under production conditions, with a fixed base recipe and stepwise sodium sulfonate dosage (Table 2).

Table 1 – Sample mixtures

Sample	Cement, g	Sand, g	Sodium sulfonate, % of cement weight	W/C
1*	400	1200	0.00	0.45
2	400	1200	0.05	0.45
3	400	1200	0.10	0.45
4	400	1200	0.15	0.45
5	400	1200	0.20	0.45
6	400	1200	0.25	0.45

* *Reference sample*

2.2 Mixing and specimen preparation (Stage A)

For each batch, component proportions were calculated for a single mix. Sodium sulfonate was first dissolved in a portion of the mixing water, then combined with the remaining water. Dry materials were mixed in a laboratory mixer for 60-90 s, after which the sulfonate solution was introduced and mixing continued for 2-3 min until a homogeneous mixture was obtained. The mixture temperature and total mixing time were recorded.

Specimens were cast into molds of 100×100×100 mm for compressive strength testing and 70×70×40 mm for abrasion testing. Molds were filled in one or two layers with light tamping (without intense vibration). The surfaces were leveled, covered with plastic film, and kept in molds for 24 ± 4 h at 20 ± 2 °C. After demolding (24-48 h), specimens were cured under natural conditions at 20-25 °C and relative humidity ≥ 50% until testing at 28 days.

2.3. Pilot/production compositions and curing (Stage B, D700)

Pilot compositions (GB1-GB4) were produced under the technological conditions of Batys Story Engineering, LLP (Uralsk, Kazakhstan) for a designed density D700 [7], with sodium sulfonate introduced into the dry mixture as a structure-forming additive, guided by [8]. The fixed base recipe and the sodium sulfonate variation are summarized in Table 2.

Table 2 – Pilot/production compositions (Stage B, designed density D700)

Sample	Sand, kg	Cement, kg	Water, l	Caustic soda, kg	Aluminum powder, kg	Sodium sulfonate content, %
GB1*	403	310	260	3	0.55	-
GB2	403	310	260	3	0.55	10
GB3	403	310	260	3	0.55	20
GB4	403	310	260	3	0.55	30

* *Reference sample*

After molding, pilot specimens were subjected to heat treatment in a drying chamber at 60 °C before subsequent testing.

2.4. Compressive strength testing

Compressive strength was determined in accordance with [9] using a hydraulic press (maximum capacity 1000 kN). Before testing, specimen surfaces were cleaned, and dimensions were measured. The load was applied at 0.5-0.8 MPa/s until failure. The compressive strength test setup is shown in Figure 1.

Figure 1 – Testing aerated concrete samples for compressive strength

2.5. Abrasion resistance testing

Abrasion resistance was measured on 70×70×40 mm specimens (Stage A) and, for the pilot study, by mass-change measurements using the IB-1 device. Abrasion testing was conducted in accordance with [10], using a rotating-disc abrasion configuration with quartz sand (0.5-1.0 mm) and an applied load of approximately 294 N (30 kgf). After testing, specimens were cleaned and dried at 105 ± 5 °C to constant mass. Abrasion was quantified by mass loss and, where required, converted to volumetric abrasion using specimen density. The abrasion test setup is shown in Figure 2.

Figure 2 – Testing aerated concrete samples for abrasion resistance

3. Results and Discussion

3.1. Effect of sodium sulfonate dosage in laboratory mixtures

The compressive strength of non-autoclaved aerated concrete increased with sodium sulfonate dosage up to an optimum range, after which the strength began to decline. This trend is summarized in Table 3, where the reference mixture without an additive shows a 28-day compressive strength of 1.5-2.0 MPa, while mixtures with 0.10-0.15% sodium sulfonate reach 2.3-2.7 MPa; at 0.20% and above, the strength decreases, and the structure is reported to deteriorate at >0.25%.

Table 3 – Dependence of aerated concrete properties on sodium sulfonate dosage (laboratory series)

Sodium sulfonate dosage, % by cement mass	Compressive strength after 28 days, MPa	Note
0.00	1.5-2.0	Basic level
0.05	2.0-2.2	Slight improvement
0.10	2.3-2.5	Optimal structural improvement
0.15	2.5-2.7	Maximum positive effect
0.20	2.4-2.6	Slight decline due to overcompaction
>0.25	2.0-2.2	Structure deteriorates, overmoistening

The same direction of influence is reflected in the broader set of property changes attributed to sodium sulfonate (workability, pore size, density, thermal conductivity, and water absorption), indicating that the additive improves mixture plasticity and pore uniformity while lowering bulk density and thermal conductivity, with a slight increase in water absorption (Table 4).

Table 3. Changes in aerated concrete properties when sodium sulfonate is introduced

Property	Direction of change	Without additive	With additive	Comment
Plasticity of mixture	Increases	14–16 cm cone settlement	17–19 cm	Improved formability and homogeneity
Porosity uniformity	Increases	Pore size 1.2–1.8 mm	Pore size 0.8–1.2 mm	More stable pore structure due to foam stabilization
Bulk density (kg/m³)	Decreases	580–600	520–540	Material becomes lighter; thermal insulation improves
Compressive strength (MPa)	Increases (~5–10%)	2.8–3.0	3.1–3.3	Structure compaction and stronger bonding
Thermal conductivity (W/(m·°C))	Decreases	0.135–0.145	0.115–0.125	Lower density + better pore uniformity
Water absorption (% by mass)	Slightly increases	32–34	35–37	Increased open porosity

The strength-dosage relationship is also visualized in Figure 3, which indicates that the maximum strength occurs at approximately 0.10-0.15% sodium sulfonate.

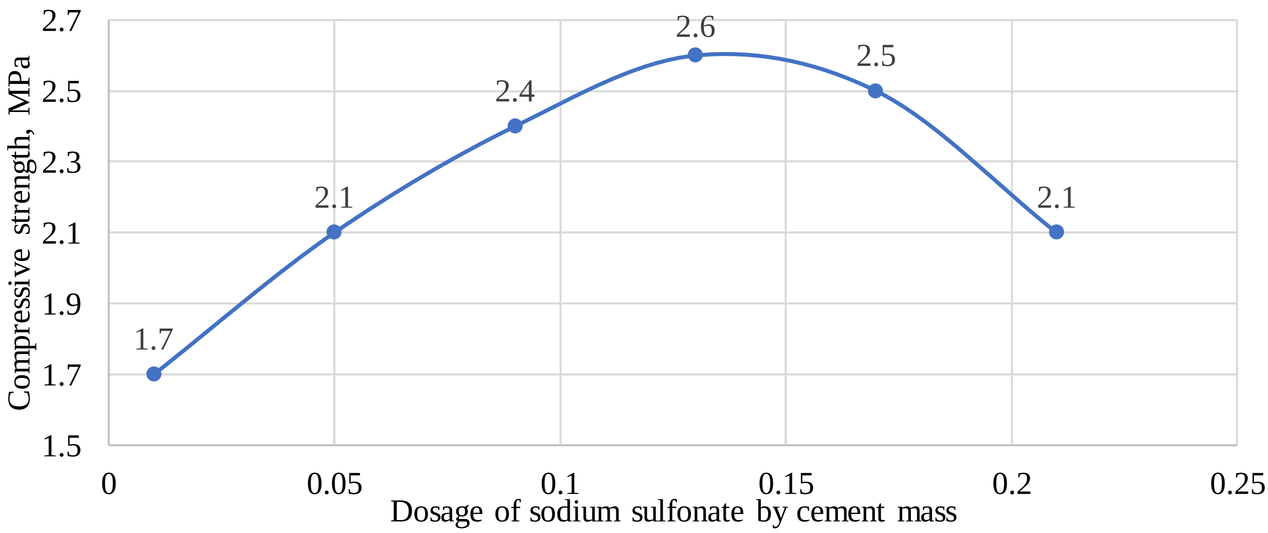

Figure 3 – Dependence of aerated concrete strength on sodium sulfonate content

3.2. Comparative performance of production compositions (GB1-GB4)

For the set of production compositions labeled GB1-GB4, the measured average density ranged from 610 to 740 kg/m^3, while compressive strength varied between 2.0 and 2.5 MPa (Table 4). The highest structural quality coefficient (SQC) among these compositions was reported for GB3 (0.034), indicating the best strength-to-density balance within this group.

Table 5 – Comparison of properties of aerated concrete compositions (GB series)

Sample	Average density, kg/m^3	Compressive strength, MPa	SQC
GB1*	610	2.0	0.020
GB2	740	2.3	0.025
GB3	700	2.5	0.034
GB4	650	2.2	0.023

** Reference sample*

A focused comparison between the reference and the best-performing composition again shows higher strength and SQC in GB3 than GB1.

3.3. Compressive strength of production samples

When compressive strength was reported for GB1-GB4 with reference to [9], the values were in the range of 5.81-6.72 MPa, with the maximum strength recorded for GB3 (6.72 MPa) (Figure 4).

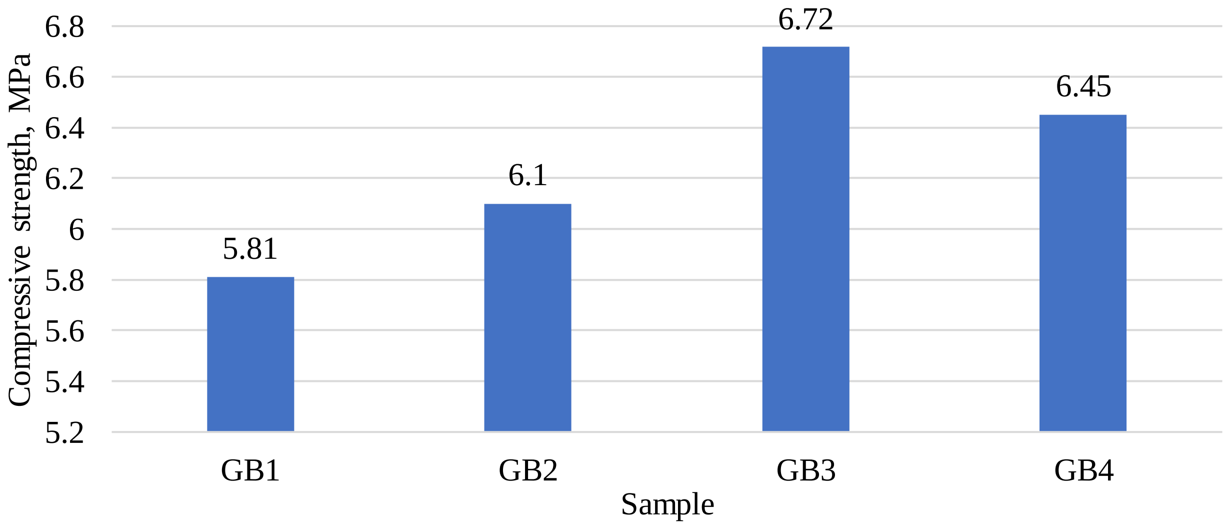

Figure 4 – Results of compressive strength tests on aerated concrete samples (GB series)

Overall, the abrasion results confirm a stable positive effect of sodium sulfonate on surface wear resistance across the modified compositions, with GB3 demonstrating the best performance in this set.

3.4. Abrasion resistance

Abrasion resistance results (mass-loss method) indicate that sodium sulfonate improves wear resistance by reducing the abrasion value from 0.84 g/cm² (GB1, grade G2) to as low as 0.71 g/cm² (GB3, grade G1) (Figure 5).

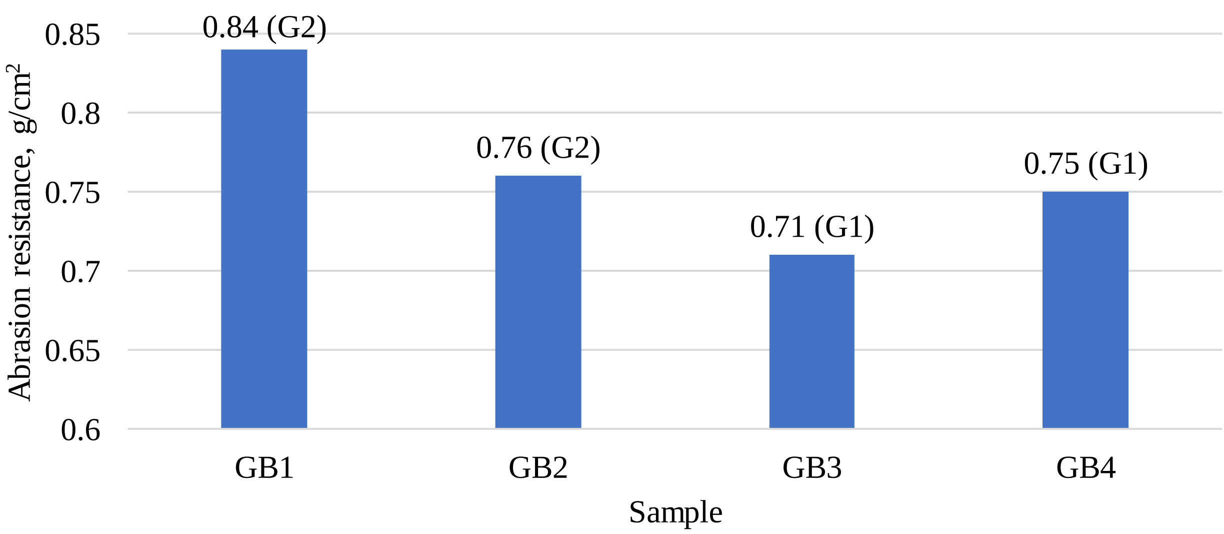

Figure 4 – Results of testing aerated concrete samples for abrasion resistance (GB series)

Overall, the abrasion results confirm a stable positive effect of sodium sulfonate on surface wear resistance across the modified compositions, with GB3 demonstrating the best performance in this set. Based on the data presented in Figure 4, we can conclude that the addition of sodium sulfonate affects the abrasion resistance of aerated concrete samples. The control composition (GB1), which does not contain additives, showed abrasion resistance at the level of 0.84 g/cm^2, which corresponds to grade G2 according to [10]. The addition of sodium sulfonate to compositions GB2-GB4 led to a noticeable decrease in abrasion resistance. Thus, sample GB2 showed a decrease in abrasion resistance to 0.76 g/cm^2, which also corresponds to grade G2, but indicates a slight improvement compared to the control sample. The greatest reduction in abrasion was observed in sample GB3, where this indicator was 0.71 g/cm^2, which allowed it to be classified as grade G1, i.e., a higher class in terms of abrasion resistance. A similar effect is observed in composition GB4 (0.75 g/cm^2, grade G1), which confirms the stable positive effect of the additive on the wear resistance of the material. The results show that as the amount of sodium sulfonate increases, the abrasion resistance of aerated concrete decreases: from 0.84 g/cm^2 in the control sample to 0.71 g/cm^2 in composition GB3, which indicates an increase in the strength of the material.

4. Conclusion

This study evaluated sodium sulfonate as a structuring (surface-active) additive for non-autoclaved aerated concrete, focusing on how dosage affects strength development and performance indicators relevant to practical block production.

In the laboratory dosage series, the compressive strength increased with sodium sulfonate content up to an optimum range and then declined at higher dosages: the reference mixture (0.00%) reached 1.5-2.0 MPa at 28 days, while mixtures with 0.10-0.15% sodium sulfonate achieved 2.3-2.7 MPa; at 0.20% and above, the strength trend decreased and the structure was reported to deteriorate at >0.25%. The broader property trends attributed to sodium sulfonate indicate improved mixture plasticity and pore uniformity, reduced bulk density and thermal conductivity, and a slight increase in water absorption, which together reflect the additive's role in stabilizing the porous structure and enhancing thermal efficiency.

In the production verification series (GB1-GB4, designed density D700), the best overall balance of density and strength was obtained for GB3, which demonstrated the highest structural quality coefficient (0.034) among the tested compositions. Strength testing of GB-series samples also indicated values of 5.81-6.72 MPa, with the maximum recorded for GB3 (6.72 MPa). Importantly, sodium sulfonate improved wear resistance: abrasion decreased from 0.84 g/cm^2 (GB1, grade G2) to 0.71 g/cm^2 (GB3, grade G1), confirming a stable positive effect on surface durability for the modified compositions.

Overall, sodium sulfonate is an effective additive for improving the performance of non-autoclaved aerated concrete by enhancing strength (within an optimal dosage range) and reducing abrasion. Based on the dosage study, a sodium sulfonate content around 0.10-0.15% (by cement mass) can be recommended as a practical optimum to achieve the most favorable strength response while maintaining stable pore formation.

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