**Comprehensive assessment of portland cement quality parameters based on Sharg‘un coal ash waste**

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**Abstract.** This study presents the production of D20 400-grade cement at Sherobod Cement Plant using Sharg‘un coal ash waste. The main aim was to reduce clinker consumption and energy use while promoting environmental sustainability. Sharg‘un coal ash was used as a technogenic mineral additive, and cement samples with varying proportions were tested to determine the optimal content. A 5% addition was found most effective, yielding cement with superior physical, chemical, mineralogical, and mechanical properties compared to conventional cement. Quality indicators, including density, specific surface area, bulk density, compressive strength, setting time, and volumetric stability, were evaluated through statistical and instrumental analyses. Infrared (IR) spectroscopy, thermogravimetric analysis (TGA), and differential thermal analysis (DTA) confirmed the compositional and thermal stability of the samples. The results demonstrate the efficiency and practical potential of using technogenic waste in cement production.

**INTRODUCTION**

In Uzbekistan, significant scientific and practical results have been achieved in the production and application of Portland cement based on local raw materials. Research in this area is crucial for obtaining high-grade, import-substituting cement, modernizing and diversifying the chemical industry, and developing new products while improving quality standards.[1]

The cement industry is a key component of any national infrastructure. Among modern construction materials, cement plays an essential role, being widely used in housing, industrial facilities, transport, and energy infrastructure. In Uzbekistan, the demand for cement continues to grow due to large construction projects, industrial zones, and infrastructure programs. The country’s favorable geostrategic location and abundant natural resources provide opportunities not only to meet domestic demand but also to produce competitive products for regional and international markets. At the same time, global ecological standards, the need for energy efficiency, and the utilization of industrial waste require new technological solutions. [2]

One effective method for energy saving in Portland cement production is grinding clinker with mineral additives such as pozzolans, fly ash, or slag. Such additives improve the quality and stability of cement. Studies have shown that the inclusion of active mineral additives, such as river sands or zeolite rocks, positively affects cement properties while reducing cement consumption and CO₂ emissions. [3]

This study investigates the potential use of Sharg‘un coal ash waste as a technogenic additive for producing sustainable construction materials. Cement samples were prepared with 3%, 3.5%, 3.8%, and 5% Sharg‘un coal ash, maintaining a constant water-cement ratio. The samples were analyzed comprehensively for physical, chemical, mechanical, durability, and microstructural properties to evaluate the suitability of Sharg‘un coal waste for sustainable construction. [4]

Industrial waste pollution is one of today’s pressing environmental issues. Only a small portion of industrial waste is recycled, making its reuse in other sectors important. Using waste as a partial replacement for clinker or cement in concrete not only reduces pollution but also lowers production costs. For example, researchers at Lugansk University have studied the use of technogenic waste from the Donbass region as cement additives, examining their effects on strength, technological and operational properties, durability, and setting kinetics. [5]

In Uzbekistan, over a billion tons of rocks and technogenic waste have accumulated, which can serve as raw materials for silicate and construction materials. Prof. M.M. Aripova and colleagues have shown that 67% of rocks obtained from open-pit mining are suitable for construction materials, including 30% for gravel, 24% for cement, and 16% for ceramic products. Recycling waste strengthens the country’s mineral base, addresses regional ecological issues, and conserves natural resources. [6]

In this study, cement samples were produced at Sherobod Cement Plant in Surxondaryo region using Sharg‘un coal ash. The physical-chemical properties were analyzed using infrared (IR) spectroscopy, thermogravimetric analysis (TGA), and differential thermal analysis (DTA).

**Materials and Methods:** In the production of D20 400-grade cement at Sherobod Cement Plant, clinker, 13.2% limestone, 3.5% gypsum, and 3.8% slag (as technogenic waste) were blended and ground in a ball mill. This mixture yielded SEM II/A-I 32.5N Portland cement. The use of technogenic waste helps save natural raw materials, reduce energy consumption, and lower environmental impact. [7]

This research investigated the potential of substituting slag with Sharg‘un coal ash in cement. The additive was selected to reduce energy consumption during clinker production, optimize raw material costs, and improve the quality properties of the resulting cement. The chemical and mineral composition of Sharg‘un coal ash was determined using X-ray fluorescence analysis, and the main oxide composition is presented in Table 1.

**TABLE 1**. Oxide Composition of Sharg‘un Coal Ash Waste (Based on X-ray Fluorescence Analysis)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Mass of oxides % | | | | | | | |
| SiO2 | Fe2O3 | Al2O3 | K2O | CaO | S | TiO | Other oxides |
| 56,779 | 3,341 | 23,147 | 13.272 | 0,769 | 0,15 | 2,077 | 0,465 |

Analysis of the composition of Sharg‘un coal ash waste shows that its main components are 56.779% SiO₂ and 23.147% Al₂O₃. This mineral additive exhibits pozzolanic properties.

Pozzolanic activity refers to the ability of silicate or silicate-aluminate materials to react slowly with lime (Ca(OH)₂) in the presence of water, forming cementitious (hydration) products, mainly calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH). Simply put, pozzolanic materials are not strong binders on their own, but they react with the Ca(OH)₂ in hydrated cement to form secondary reinforcing phases, enhancing overall strength. [8]

**EXPERIMENTAL RESEARCH**

**IR Spectral Analysis.** Cement samples containing 5% coal ash waste were analyzed using FTIR. The broad peak observed at 3427 cm⁻¹ corresponds to O–H stretching vibrations, indicating the presence of hydrated phases (C–S–H, Ca(OH)₂). Peaks at 1427 cm⁻¹ and 874 cm⁻¹ are associated with carbonate groups, suggesting carbonation of the cement. The vibration recorded at 1217 cm⁻¹ corresponds to sulfate groups, likely indicating the presence of gypsum or ettringite. The intense peak at 947 cm⁻¹ is attributed to Si–O stretching vibrations, confirming the presence of the C–S–H phase. Peaks in the 720–600 cm⁻¹ range correspond to aluminosilicate structures, while the low-frequency peaks at 517–449 cm⁻¹ are associated with Ca–O and Si–O–Ca bonds, indicating clinker phases (alite, belite). [9], [10] Additionally, weak peaks at 2350 cm⁻¹ and 2900–2850 cm⁻¹ were observed, corresponding to CO₂ and C–H vibrations characteristic of coal ash, indicating the presence of organic components.

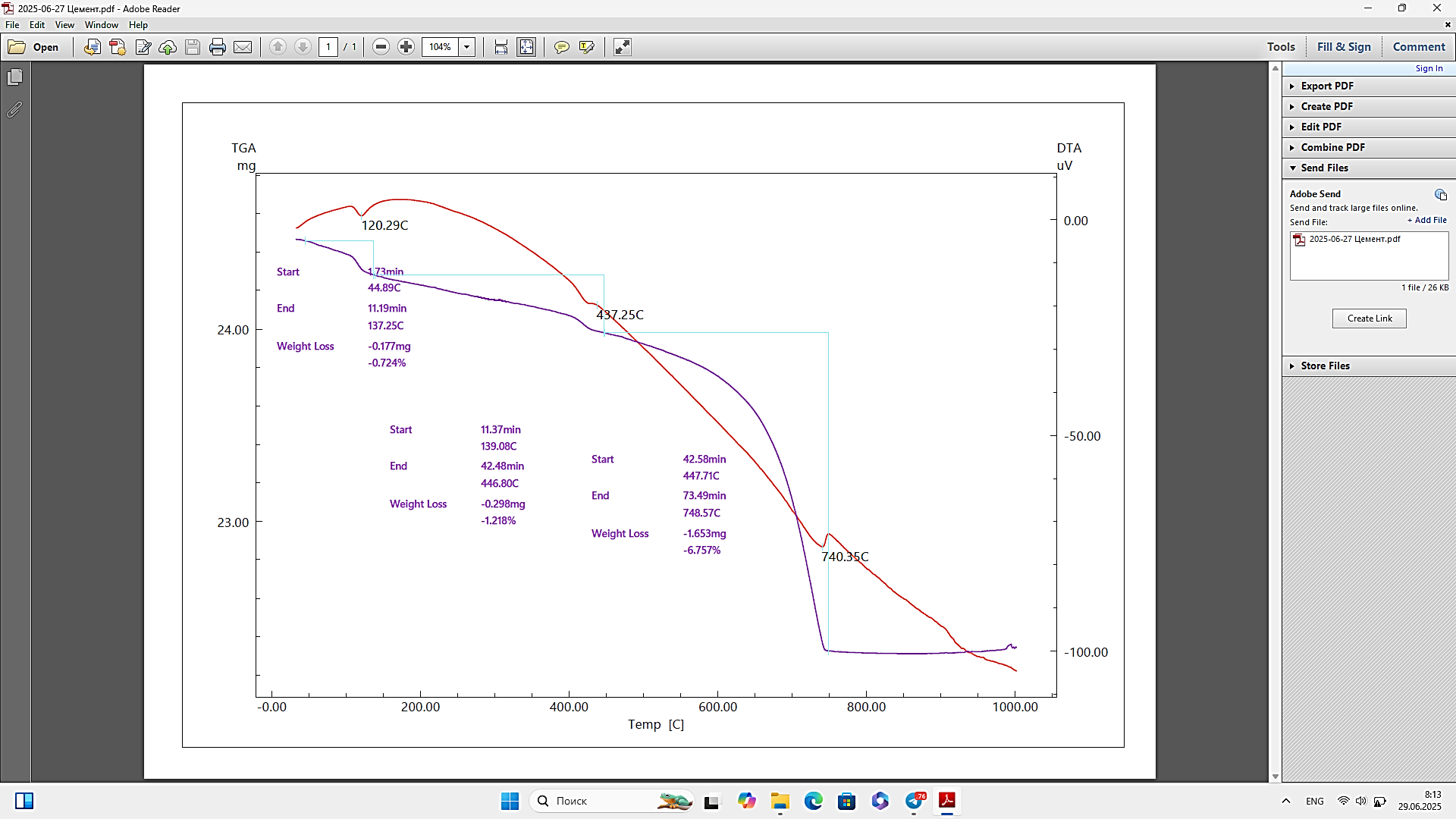
Overall, the addition of 5% coal ash waste did not negatively affect the chemical or structural composition of the cement. Therefore, this additive is suitable for producing modified cement and can be effectively used as an alternative material.



**FIGURE 1.** FTIR Spectrum of Cement Sample Prepared with 5% Coal Ash Waste.

TGA and DTA Analysis. The results were evaluated as follows:

1. Stage I (44.89°C – 137.25°C)
   * Temperature range: 44.89°C – 137.25°C
   * Mass loss: 0.177 mg (0.724%)
   * DTA effect: Endothermic peak at 120.29°C
   * Note: This stage corresponds to the evaporation of free and bound water in the sample. [11]
2. Stage II (139.08°C – 446.20°C)
   * Mass loss: 0.298 mg (1.218%)
   * DTA reaction: Low-intensity endothermic process
   * Note: Decomposition of hydrated phases in the cement occurs at this stage (e.g., decomposition of Ca(OH)₂). [14]
3. Stage III (447.71°C – 748.57°C)
   * Mass loss: 1.653 mg (6.757%)
   * DTA peak: Strong endothermic effect at 740.5°C
   * Note: Decomposition of carbonates (mainly CaCO₃) occurs at this stage, accounting for the major portion of mass loss. [13]



**FIGURE 2**. **TGA and DTA Analysis Results.**

The total mass loss was approximately 8.7%, indicating that the coal ash waste is relatively stable at high temperatures, although carbonate compounds are present. The TGA/DTA results show that the cement sample containing coal ash waste undergoes stepwise thermal decomposition up to 1000°C. The main changes occurred in the 400–750°C range, corresponding to the decomposition of carbonates. This waste helps maintain the stability of hydraulic phases in cement and can be used as an environmentally safe alternative additive. [15]

Preparation of Cement Sample Based on Sharg‘un Coal Ash Waste: In the laboratory, a 3 kg Portland cement sample was prepared using Sharg‘un coal ash waste, consisting of 78.3% clinker, 13.2% limestone, 3.5% gypsum, and 5% Sharg‘un coal ash waste. By mass, 2349 g of clinker, 396 g of limestone, 105 g of gypsum, and 150 g of coal ash waste were used. The mixture was ground in a ball mill for 1 hour and then sieved through a 0.08 mm mesh. The exact composition of the mixture was:

* Clinker – 2349 g
* Limestone – 396 g
* Gypsum – 105 g
* Sharg‘un coal ash waste – 150 g

The physical and chemical properties of the resulting cement samples were studied in the chemical laboratory of Sherobod Cement Plant. [16]

Determination of Additive Content: To determine the optimal additive content, thermal analysis tests were carried out in the chemical laboratory. Two crucibles were taken, each containing 5 g of cement sample with Sharg‘un coal ash waste.

The experimental procedure was as follows:

* The sample in the first crucible was heated in a muffle furnace at 973ºC for 1 hour.
* The sample in the second crucible was heated in a muffle furnace at 550ºC for 1 hour.
* After thermal treatment, the crucibles were cooled, and the samples were weighed again on an analytical balance.

Results:

* Mass loss at 973ºC: 0.3609 g
* Mass loss at 550ºC: 0.0731 g

The total mass loss upon heating (PPP) of the cement was then calculated.

PP=7,218%

The resulting value represents the mass loss of the cement after heating. In the next step, the additive content is determined as follows: the mass loss at 575ºC is subtracted from the mass loss at 975ºC, the difference is then converted to a percentage and multiplied by the constant 2.27 (CaCO₃/CO₂). The resulting value is divided by the sample mass (5 g) to obtain the additive content. [17]

m=0,3609-0,0731=0,2878

=13,0661%:

According to the determined results, the additive content in the cement sample prepared with Sharg‘un coal ash waste was 13.0661%. This value meets the standard requirements for D20 400-grade cement and confirms that Sharg‘un coal ash waste can be effectively used as a technogenic additive in Portland cement production. [18]

**Density Determination:** Tests conducted using a high-precision measurement device from Micromeritics (USA) showed that the density of the cement sample containing 5% Sharg‘un coal ash waste is 3.08 g/cm³. This indicates that the technogenic additive is optimally integrated into the cement matrix and does not negatively affect the material’s density properties. [19]

**Specific Surface Area Determination:** The specific surface area was measured using an analyzer based on the Blaine air-permeability method. After determining the density of the cement sample, the required sample weight (m) for the analyzer was calculated using the following formula:

m=ρ×K×0.5

Here:

* ρ = 3.08 g/cm³ — density of the sample;
* K = 73.652 — constant coefficient (calibration constant for the Blaine analyzer);
* 0.5 — coefficient applied according to the instrument’s calculation formula.

Based on the calculations, the resulting value is:

m=3.08×73.652×0.5=113.79 gm

The determined sample mass was placed on the specially installed filter paper of the analyzer, and the measurement was performed. According to the test results, the cement sample containing 3.8% Sharg‘un coal ash waste exhibited a specific surface area of 3277 cm²/g. [20]

The obtained results were compared with the characteristics of conventional SEM II/A-I 32.5N Portland cement. The comparison showed that the cement sample produced with coal mining waste had specific surface area values close to those of conventional cement, confirming the effectiveness of the applied technogenic additive. A summary of the measured parameters is presented in Table 2.

**TABLE 2.** Density and Specific Surface Area of Clinker, Conventional Cement, and Cement Samples Prepared with Sharg‘un Coal Ash Waste

|  |  |  |  |
| --- | --- | --- | --- |
| No | Samples | Density of samples g/cm3 | Specific surface area of ​​samples g/cm2 |
| 1 | Clinker | 3,11 | 3175 |
| 2 | Conventional cement | 3,09 | 3161 |
| 3 | Cement Sample Produced Using Sharg‘un Coal Ash Waste | 3,08 | 3277 |

**Evaluation of Physical and Mechanical Properties of Cement and Cement Paste Samples:** Tests were conducted to assess the setting kinetics of cement paste prepared with Sharg‘un coal ash waste. For the experiments, 450 g of cement sample was accurately weighed using an analytical balance. Water was added in the range of 22–28% relative to the cement mass to prepare the paste. The standard Vicat apparatus was used to determine the setting times. [21]

To determine the initial setting time, a special needle weighing 300 g was lowered into the cement paste every 10–15 minutes. The start of the initial setting was indicated when the needle penetrated to a depth of 3–5 mm. The final setting time was recorded when the needle could no longer penetrate within the 0.05–0 mm range.

According to current standards, the initial setting time of Portland cement should not exceed 45 minutes, and the final setting time should not exceed 10 hours. The results of setting time and water demand for the cement samples obtained in this study are presented in Table 3.

**TABLE 3. Setting Time and Water Demand of Cement Sample Prepared with Sharg‘un Coal Ash Waste.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| № | Daily samples | Start of bite (min) | End of bite (min) | Amount of water required (ml) |
| 1 | Clinker | 155 | 200 | 127 ml |
| 2 | Conventional cement | 170 | 220 | 128 ml |
| 3 | Cement Sample Produced Using Sharg‘un Coal Ash Waste | 195 | 250 | 132 ml |

The analysis of the obtained results showed that the cement sample prepared with Sharg‘un coal ash waste exhibited water demand and setting times very close to the technological characteristics of conventional SEM II/A-I 32.5N cement and standard clinker samples. This confirms that the technogenic material used as an additive has optimal hydraulic and technological properties. [21]

**Determination of Portland Cement Paste Expansion Using the Le Chatelier Ring:** The volumetric change (expansion) of cement paste was determined using the Le Chatelier method. First, the prepared cement paste was placed into the Le Chatelier ring and covered on the top and bottom with glass plates. The test began in a water environment at 20°C, and the samples were kept in water for 24 hours. After this period, the distance between the tips of the needles was measured, and the initial expansion value was recorded. [21]

In the next step, the samples in the ring were subjected to boiling in the Le Chatelier apparatus at 100°C for 4 hours. After heat treatment, the samples were cooled, and the distance between the needle tips was measured again. Based on these measurements, the expansion of the cement paste was calculated in millimeters. The determined expansion results are summarized in Table 4.

**TABLE 4.** Results of Cement Paste Expansion Determined Using the Le Chatelier Ring

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| № | Samples | Initial width of Le Chatelet ring, mm | Width of Le Chatelet ring after 24 hours in water, mm | Width of Le Chatelet ring after boiling for 4 hours, mm |
| 1 | Clinker | 11 | 12 | 13 |
| 2 | Conventional cement | 8 | 9 | 10 |
| 3 | Cement Sample Produced Using Sharg‘un Coal Ash Waste | 8 | 9 | 10 |

The main purpose of studying the expansion of cement samples using the Le Chatelier ring is to determine that the amount of free calcium oxide (CaO) in the cement does not exceed the standard limits. It is known that excessive free CaO can cause undue volumetric expansion during the cement hydration process, which may compromise the dimensional stability of the final product. [22]

According to the study results, cement samples containing Sharg‘un coal ash waste did not show a significant concentration of oxides causing expansion in the Le Chatelier ring. As a result, the volumetric expansion values of these cement samples were nearly identical to those of conventional Portland cement samples [28-57]. This confirms that the technogenic material used as an additive is suitable from a technological safety perspective and has practical applicability. **Determination of Compressive and Flexural Strength of Cement Samples:** [21]

To classify the cement, mechanical tests were conducted according to the requirements of the GOST 31108-2020 state standard. For the tests, the prepared mixtures consisted of 1350 g of polyfraction sand, 450 g of cement, and 225 g of water, prepared according to a 3:1:0.5 mass ratio. Standard prismatic blocks measuring 40×40×160 mm were cast from the prepared cement paste.

The samples were stored under standard conditions, and mechanical strength tests were carried out after curing for 2, 7, and 28 days. All compressive and flexural strength tests were performed using modern press equipment at the Sherobod Cement Plant. The results of the mechanical tests are summarized in Table 5.

**TABLE 5.** Compressive and Flexural Strength of Cement Samples Prepared with Sharg‘un Coal Ash Waste

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| № | Samples | 2 days (N/mm2) | 7 days (N/mm2) | 28 days (N/mm2) |
| 1 | Clinker | 20,8 | 32,9 | 48,7 |
| 2 | Conventional cement | 14,9 | 27,1 | 32,9 |
| 3 | Cement Sample Produced Using Sharg‘un Coal Ash Waste | 16,7 | 27,9 | 38,9 |

**RESEARCH RESULTS**

The obtained experimental results indicate that the SEM II/A-I 32.5N cement sample developed using Sharg‘un coal ash waste can be successfully used as a technogenic mineral additive in conventional cement. The compressive strength tests showed that this additive does not negatively affect mechanical strength; on the contrary, it contributes to maintaining the structural integrity of the cement matrix. [22]

The mechanical strength values obtained fully comply with the current requirements of the GOST 31108-2020 state standard. Moreover, the use of Sharg‘un coal ash waste in the technological process is of particular importance as an ecological and resource-saving approach, since this technology reduces the consumption of natural raw materials, enables secondary processing of waste materials, and decreases anthropogenic environmental impact. [23]

**CONCLUSIONS**

Experimental studies conducted at the Sherobod Cement Plant in Surkhandarya region confirmed that Sharg‘un coal ash waste can be successfully used as a technogenic mineral additive in the production of D20 400 grade Portland cement.

The main oxides in the coal ash waste—56.779% SiO₂ and 23.147% Al₂O₃—impart pozzolanic properties, meaning that it reacts with Ca(OH)₂ during hydration to form secondary strengthening phases.

FTIR, TGA, and DTA analyses showed that adding 5% coal ash waste does not negatively affect the chemical and thermal stability or the structural properties of the cement.

The density (3.08 g/cm³) and specific surface area (3277 cm²/g) of the cement sample with the additive are close to those of conventional SEM II/A-I 32.5N cement, indicating successful integration of the technogenic additive into the cement matrix.

The setting times (initial and final) and water demand of the cement paste meet standard requirements, while the expansion measured using the Le Chatelier ring shows that the free CaO content does not exceed normative limits, ensuring volumetric stability of the cement.

Mechanical tests indicated that the cement samples containing coal ash waste fully comply with standards in terms of compressive and flexural strength and maintain structural integrity of the matrix.

The use of Sharg‘un coal ash waste reduces production costs, conserves natural raw materials, enables recycling of industrial waste, and decreases environmental impact. **Overall conclusion:** Sharg‘un coal ash waste can be effectively used as an environmentally safe, resource-efficient technogenic additive in Portland cement production.

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