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Original Article

Increasing the Efficiency of Cement based on Asphalt Plant Filter Waste

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Abstract - *This article presents the production process of D20 400 grade cement at the Sherabad Cement Plant, located in the Surkhandarya region. In the manufacturing process, technogenic waste obtained from industrial enterprises of the Surkhandarya region was utilized. The main objective of this study is to reduce energy consumption in clinker production, enhance environmental sustainability, and minimize the use of natural resources. For this purpose, the filter waste from an Asphalt Plant was selected as a technogenic additive. The physical and chemical properties of the cement samples produced with the inclusion of this filter waste were examined, and the optimal production ratio was determined. The properties of the obtained cement samples were analyzed and compared with those of conventional cement. Based on the research results, it was found that adding 7% Asphalt Plant filter waste to the composition of D20 400 grade cement yielded the most favorable outcome. Additionally, key indicators such as density, specific surface area, liter The ight, compressive strength, sieve analysis, setting time, and volume stability of the resulting cement samples are evaluated. The obtained results were further analyzed using IR Spectroscopy, Thermogravimetric Analysis (TGA), and Differential Thermal Analysis (DTA).*

Keywords - *Sherabad Cement Plant, Clinker, Asphalt Plant, Filter Waste, IR Spectroscopy, TGA and DTA analyses.*

1. Introduction

Rapid urbanization has intensified environmental pollution, increasing interest in the *zero-waste city* concept, which promotes the efficient reutilization of industrial solid waste to support sustainable development [1]. An economic and environmental comparison of a novel industrial waste-based hardening agent and Ordinary Portland Cement (OPC) was conducted using 1 ton of product as the functional unit. The results indicate that Global Warming Potential (GWP) is the dominant environmental impact category. Compared with OPC, the novel hardening agent reduces total environmental impact by 69.9% and production cost by 29.32%, demonstrating clear environmental and economic advantages and highlighting its potential as a sustainable alternative to conventional cement-based materials [2, 3].

Novel supplementary cementitious materials (CDM and CDB) are produced from construction wastes and waste dolomite powder. Incorporating 10%–20% of these SCMs slightly reduced early-age strength but enhanced long-term strength and mitigated shrinkage, highlighting their potential for durable cement-based materials [4, 5]. Binary, ternary, and quaternary mortar blends were prepared using silica fume, fly ash, and GGBS to reduce cement consumption. Results show that the binary blend exhibited the highest performance, with optimal 28-day compressive strength achieved at 20% fly ash, 30% GGBS, and 10% silica fume, while ternary blends outperformed the control and quaternary mixes showed no significant improvement [6].

The suitability of oil-bleached smectite clay waste for Limestone Calcined Clay Cement (LC3) was investigated. LC3 containing 10%-30% Calcined Clay exhibited medium pozzolanic activity, higher cumulative hydration heat, and 28-day compressive strengths above 50 MPa, outperforming OPC, with alumina phases contributing to the formation of Hemicarboaluminate and Monocarboaluminate [7, 8].

Stone industry waste poses land, safety, and resource challenges. A binder (CGF) based on Calcium Carbide residue, GGBS, and fly ash was developed to solidify stone waste, achieving higher unconfined compressive strengths (2.93 and 4.42 MPa at 7 and 28 days) than OPC. The strength improvement is attributed to alkali-activated formation of C-S–H, C-A-H, and C-A-S–H gels, while primary stone minerals remained intact [9-12]. Waste eggshell was investigated as a partial replacement for limestone in Portland cement mortars at 15% and 35% levels. Mortars with 15% eggshell achieved similar compressive strength as limestone mixes, improved hydration, and reduced embodied carbon, energy, and cost, while 35% replacement showed slower hydration due to the eggshell membrane, indicating eggshell waste is a sustainable alternative up to 15% replacement [13-16].

The main aim of this study is to evaluate the use of asphalt plant filter waste in D20 400 cement to enhance sustainability and reduce energy and natural resource consumption, identifying 7% as the optimal addition for improved physical and chemical properties.

2. Materials and Methods

At the Sherobod Cement Plant, D20 400-grade cement clinker is ground together with 13.2% limestone, 3.5% gypsum, and 3.8% slag (considered a technogenic waste) in a ball mill to produce Portland cement of type CEM II/A-I 32.5N. The rational use of these by-products helps to conserve natural resources and reduce the negative impact on the environment. In our research, filter dust obtained from asphalt plants in Termez, Surkhandarya region, was used as an additional material in the clinker production process with the aim of reducing energy consumption and improving cement quality. Table 1 presents the oxide composition of these wastes determined by X-ray analysis.

Table 1. Oxide content obtained from X-ray analysis of our waste products

No	Composition of waste products from the Termez district asphalt plant	Unit of measurement	Quantity	According to the requirements of GOST 5382-2019
1	Si_2O	%	33,29	
2	Al_2O_3	%	5,31	
3	Fe_2O_3	%	1,76	
4	CaO	%	24,80	
5	MgO	%	0,71	Should not exceed 5%
6	SO_3	%	1,55	
7	Na_2O	%	0,90	
8	K_2O	%	2,24	
9	K/K	%	29,45	
10	Total	%	100	

2.1. Methods

An IR analysis of a cement sample made from asphalt plant filter waste was conducted using IR spectroscopy. IR analysis of the cement sample was performed using a SHIMADZU IR-Fury Spectrophotometer (Japan) at 400 and 4500 cm-1.

TGA and DTA analysis-Thermogravimetric (TG) and Differential Thermal Analysis (DTA) of the cement sample physicochemical changes with temperature. The re performed using a SHIMADZU DTG-60 device (Japan). The analysis was conducted under an argon atmosphere (80 ml/min) with a heating rate of 10 °C/min.

3. Statistical Analysis

All compressive and flexural strength tests were performed on three identical specimens for each composition and curing age (2, 7, and 28 days). The reported strength values represent the arithmetic mean of the obtained results. Standard deviation was calculated to evaluate the repeatability and reliability of the experimental data.

Data processing and graphical comparison were carried out using standard spreadsheet-based statistical tools. The observed variations between samples are within acceptable experimental limits, indicating good consistency of the measurements.

3.1. Cement Sampling based on Filter Waste

In the laboratory, a 3 kg sample was prepared by mixing 13.2% Limestone, 3.5% Gypsum, and 10% Asphalt Plant Filter waste with clinker. The combined mixture was ground in a ball mill for 1 hour and then sieved through a 0.08 mm mesh.

The proportions used in the mixture are as follows: 3000 g of clinker, 396 g of limestone, 105 g of gypsum, and 300 g of filter waste. The physicochemical characteristics of the resulting samples were examined in the chemical laboratory of the Sherabad Cement Plant.

Determination of Density Using the Micrometrics Apparatus. Under laboratory conditions, the density of the cement sample prepared with 10% asphalt plant filter waste was found to be 3.08 g/cm³.

Determination of Specific Surface Area Using the Blaine Analyzer. The specific surface area of the cement sample incorporating asphalt plant filter waste was measured with a Blaine analyzer. Once the density of the cement was determined, it was multiplied by two fixed coefficients, 73.652 and 0.5, to calculate the amount of sample to be used for the test. Thus, for a density of 3.08 g/cm³, the The light of the sample is calculated as: $m = 3.08 \times 73.652 \times 0.5 = 113.79$ g.

The high sample was placed on the filter paper at the bottom of the Blaine instrument's measuring cell, and the determined density value was entered into the device. After a short measurement period, the number of particles per square centimeter was automatically displayed on the screen. As a result of the analysis, the specific surface area of the cement sample prepared with asphalt plant filter waste was determined to be 3334 g/cm³. The obtained data indicate that both the density and specific surface area of the modified cement closely correspond to those of SEM II/A-I 32.5N Portland cement. Table 2 below presents the results of the modified cement sample.

Table 2. Density and specific surface area of cement samples obtained from clinker, conventional cement, and asphalt plant filter waste

T/r	Samples	Density of samples g/cm^3	Specific surface area of samples g/cm^3
1	Clinker	3,12	3317
2	Conventional cement	3,09	3232
3	Sample made from asphalt plant filter waste	3,08	3334

3.2. Determination of Density and Specific Surface Area

Increasing cement concentration leads to an increase in density, which plays an important role in reducing the specific surface area. Generally speaking, the higher the dispersion of cement, that is, the finer it is ground, the greater its volume.

Although finer cement tends to exhibit higher strength, it can also create packaging difficulties - for example, a 50 kg bag may not physically hold 50 kg of cement if the product is excessively fine.

To prevent such issues, the fineness of cement is regulated by adjusting the sieving mechanisms within the elevator and separator systems during the grinding process [13-14]. Evaluation of Physical and Mechanical Properties of Cement and Cement Paste with Additives. To determine the setting characteristics, 450 g of cement containing Asphalt Plant Filter waste was precisely weighed using an analytical balance and mixed with water in the proportion of 22–28% by The ight to form a uniform paste.

The setting process was evaluated using a Vicat apparatus. The initial setting time was established by allowing a 300 g Vicat needle to penetrate the paste at 10-15 minute intervals. The moment when the needle penetration reached 3-5 mm signified the beginning of setting.

The final setting time was recorded once the needle penetration reduced to 0.05–0 mm, indicating complete hardening of the paste [15-16]. According to established standards, Portland cement should not begin setting earlier than 45 minutes and should fully set within 12 hours. The water requirement and setting time results obtained for the prepared sample are presented in Table 3.

Table 3. Setting the time and water requirement of the obtained cement sample

No	Daily samples	Start of bite (min)	End of bite (min)	Amount of water required (ml)
1	Clinker	145	193	135 ml
2	Conventional cement	132	180	125 ml
3	Sample made from asphalt plant filter waste	135	200	128 ml

The water demand and setting times of the obtained cement sample were re-studied. An increase in efficiency was observed, with the water consumption and setting times of the cement sample being close to the water consumption and setting times of conventional cement and clinker of SEM II/A-I 32.5N brand, using the table above.

Determination of the expansion of Portland cement paste in the Le Chatele ring. To evaluate the setting time and water demand, the Le Chatelier ring method was applied.

The remaining cement paste was carefully poured into a Le Chatelier mold, and glass plates were attached on both sides to observe the volumetric expansion of the cement paste under controlled temperature conditions of 20°C and 100°C.

The sample was then immersed in water at 20°C for 24 hours, after which the needle gap was measured again. Next, the same sample was placed in the Le Chatelier apparatus and boiled for 4 hours at 100°C.

After cooling to room temperature, the final distance on the needles was recorded once more. From these measurements, the linear expansion (in mm) of the cement paste was calculated [17, 18]. The results of the Le Chatelier expansion test for the cement paste are summarized in Table 4.

Table 4. Determination of cement paste expansion in the le chatele ring

No	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	10	11	12
2	Conventional cement	9	10	11
3	Sample made from asphalt plant filter waste	8	9	10

The main purpose of studying the expansion of a cement sample in the Le Chatelier Ring is to determine whether the free CaO content of the cement does not exceed the norm. Since the mineral additives used in our experiment did not contain oxides that expand the Le Chatelier Ring, the results in the cement samples are similar. Determination of the compressive and flexural strength of cement samples. To determine the cement grade in accordance with state standard GOST 31108-2020, a mixture was prepared consisting of 1350 g of polyfraction sand, 450 g of cement, and 225 g of water, following the standard proportion of (3:1:0.5) for sand, cement, and water, respectively. From the prepared cement paste, prismatic samples measuring 4 × 4 × 16 cm were re-cast. After curing, the samples were subjected to compressive strength tests at 2, 7, and 28 days using a standard compression testing machine. Table 5 Below Shows the Compressive Properties of Two-, Three-Day-Old, and Twenty-Eight-Day-Old Cement Samples.

Table 5. Compressive and flexural strength

No	Samples	2 days (N/mm^2)	7 days (N/mm^2)	28 days (N/mm^2)
1	Clinker	19,8	33,7	48,1
2	Conventional cement	13,9	24,7	33,1
3	Sample made from asphalt plant filter waste	20,9	32,9	42,7

From the above test results, it can be seen that the use of this Asphalt Plant Filter waste has yielded better results than conventional cement. It can be seen that the two-day samples showed 20.9 N/mm², compared to the conventional cement sample (13.9 N/mm²). From the results of this test, it can be seen that the addition of filter waste obtained within seven days slightly improved the hydration kinetics. After 28 days of curing, the compressive strength of the modified cement reached 42.7 N/mm², exceeding the minimum requirement for SEM II/A-I 32.5N cement and demonstrating stable long-term mechanical performance.

These results confirm that the Asphalt Plant Filter waste contributes positively to the mechanical properties of cement, particularly by enhancing early strength development while maintaining adequate long-term strength.

3.3. IR Analysis

IR spectrum analysis was conducted at the Sherabad Cement Plant to study the composition and structure of a cement sample obtained from the filter effluent of the asphalt plant (Figure 1).

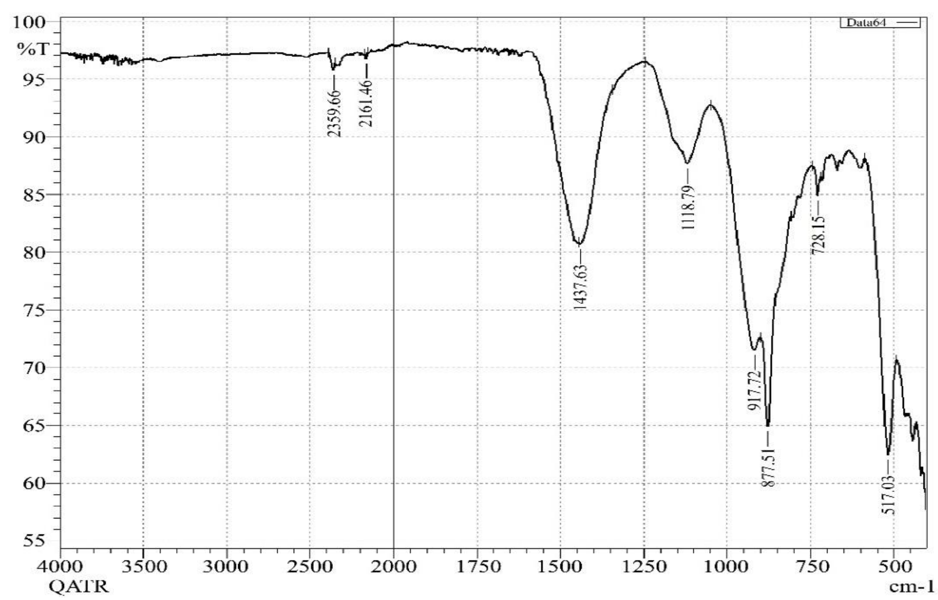

Fig. 1 IR spectroscopy analysis

This part presents the results of the compositional study of the cement specimen carried out through Fourier-Transform Infrared (FTIR) Spectroscopy. The FTIR examination was conducted to detect the characteristic. Functional groups corresponding to silicate, aluminate, and carbonate compounds existing in the material. The summarized spectral data are provided in Table 6. According to the results of the FTIR spectra analysis presented in the first figure, the presence of silicate phases (C_3S, C_2S) that characterize the strength properties of the cement, aluminate and ferrite components (C_3A, C_4AF), the presence of C–S–H and C–A–H bonds that lead to the formation of hydration products, as well as the presence of Carbonate Compounds ($CaCO_3$) can be seen.

Analysis of FTIR data shows that the hydration process of cement is normalized by these mineral phases, indicating that the used filter waste improves the properties of the cement [19, 20].

Table 6. IR spectroscopy wavenumber (cm^{-1}) analysis

Wavenumber (cm^{-1})	Bond type	Note
1437.63	C–O	The presence of calcium carbonate ($CaCO_3$) is a sign of carbonation
1118.20	Si–O–Si / Si–O–Al	Silicate and aluminosilicate phases – C_3S, C_2S
977.22	Si–O	C–S–H (calcium silicate hydrate) presence
677.51	Si–O–Al	Aluminates/ferrites – presence of C_3A, C_4AF
523.15 / 471.09	O–M	Hydrated aluminate/ferrite phases
2369.66 / 2316.16	CO_2	Carbon dioxide absorption in the atmosphere – natural carbonation

3.4. TGA and DTA Analysis

According to the results of Thermogravimetric (TGA) and Differential Thermal Analysis (DTA) of the cement sample with the addition of Asphalt Plant Filter residue in the temperature range of 30°C –600 °C, the initial mass loss occurred at 36.43°C –122.17 °C for 0.11 min –9.15 min, which was 0.156 mg (0.818%). It is known from the DTA curve that it goes from 118.12 °C to 132.47 °C, which indicates that dehydration occurs in the process. The highest decomposition occurred at 9.49 min –39.35 min and at a temperature range of 125.65°C – 421.07 °C, resulting in a mass loss of 0.161 mg (0.844%), which is associated with the decomposition of organic residues in the filter waste. In the final stages, a mass loss of 0.107 mg (0.561%) occurred at 39.63–55.66 min and at a temperature range of 424.01–580.27 °C, indicating that metal oxides and inorganic salts caused the decomposition. At 118.12 °C, an endothermic process was observed in the DTA curve, with a heat absorption of −20.25 mJ (equivalent to −11.55 J/g or −2.76 cal/g), and a signal amplitude of −2.07 µV.

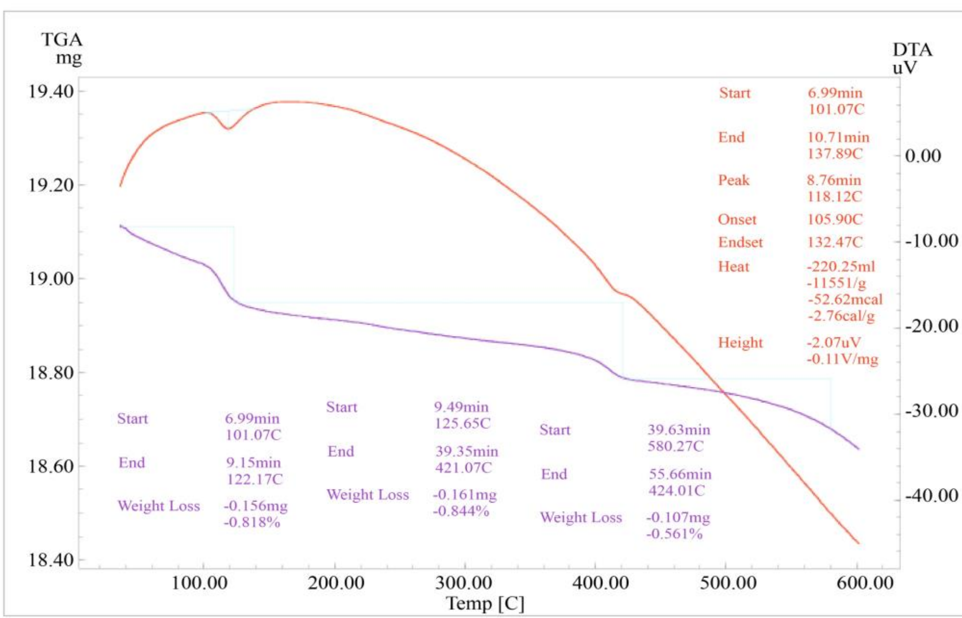

Fig. 2 Thermogravimetric (TGA) Analysis

From the results of Thermogravimetric Analysis (TGA), it can be seen that the first stage of mass loss occurred in the temperature range of 32.74–171.52 °C and took place in 15.22 minutes. During this phase, a slight decrease of 0.139 mg, equivalent to 1.761 %, was registered. The observed reduction is primarily attributed to the evaporation of hygroscopic and crystalline water, as well as the removal of minor volatile constituents [23, 24]. The next stage, the second stage, started at 173.40 °C (15.40 min) and continued until 420.78 °C (40.55 min), with a mass loss of 0.111 mg (1.406%), which can be explained by the decomposition of possibly more complex organic compounds in the composition. The final stage initiated at 420.24 °C (40.51 min) and concluded at 594.83 °C (58.38 min), with a recorded mass decrease of 0.085 mg (1.077 %). The stability of this material composition at various temperatures, its practical and industrial applicability, and its unhindered use in this field can be inferred from the TGA/DTA test results [25-37].

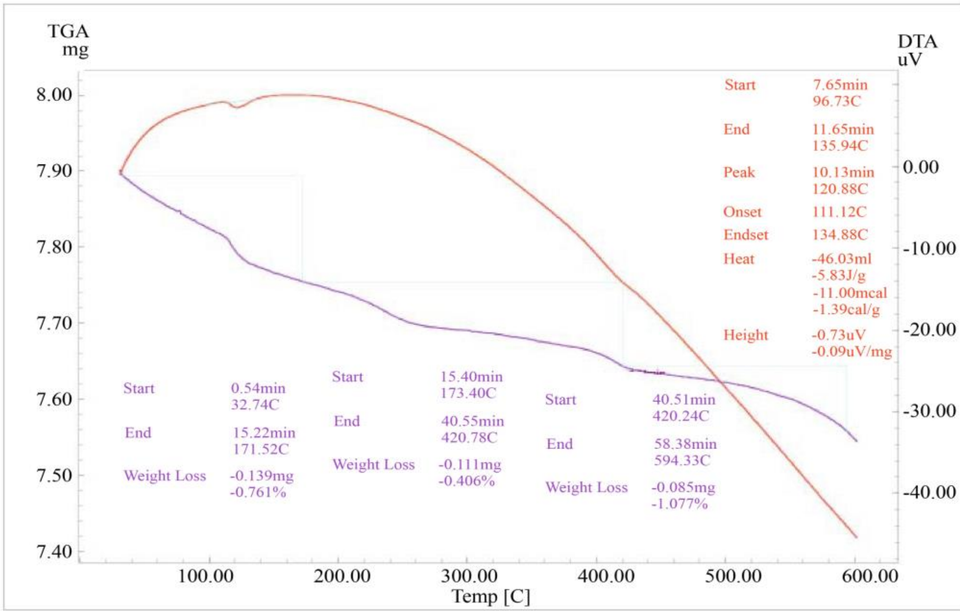

Fig. 3 Thermogravimetric (TDA) Analysis

4. Conclusion

The possibility of using 7%–10% of Asphalt Plant Filter waste as a technogenic additive was studied at the Sherabad Cement Plant, and Physicochemical, Mechanical, and instrumental analyses were performed on a cement sample obtained as a result of using 10% of filter waste. It was found that the cement had a density of 3.08 g/cm^3 and a specific surface area of 3334 cm^2/g, a compressive strength of 3.08 g/cm^3, a maximum water requirement of 128 ml at initial and final setting times of 35 and 200 minutes, and a 28-day sample with a tensile strength of 42.7 N/mm^2. In addition, FTIR analysis of the obtained sample was conducted, which showed that the composition of the cement was standard, including C_3S, C_2S, C-S-H, and $CaCO_3$. The results of TGA-DTA showed that the cement was able to maintain its physicochemical properties during heating and cooling.

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