

Article

The Effect of Fly Ash Additive on the Thermal Conductivity of Polystyrene Concrete

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Abstract: The use of fly ash in compositions as a substitute for a part of cement is economically favorable and ecologically feasible in connection with large accumulations of waste at the enterprises of the energy sector. In addition, the technology of cement production provides high-temperature treatment of mineral substances in kilns with significant emissions of carbon dioxide. One of the most effective directions of the utilization of fly ash is their use in concrete composites. The use of this material will provide the required temperature and humidity conditions in residential premises, solve the problem of “cold bridges” in structures, minimize heat losses of the structure, and increase the energy efficiency of buildings in general. At the same time, polystyrene concrete, due to its structural structure and the presence of thermally conductive concrete, has limited opportunities for thermal and physical–mechanical properties. To improve the operational properties of polystyrene concrete, it is proposed to use composite binders, including fly ash from the thermal power station of Astana. The main aim of this study is to develop compositions of polystyrene concrete with reduced thermal conductivity and improved physical and mechanical properties. The objectives of this study include the determination of characteristics of fly ash from Astana, formulation of polystyrene concrete mixtures with different proportions of fly ash, and evaluation of their thermal conductivity properties. These tasks are in line with the objectives of the ISO 50001 standard to improve energy efficiency and reduce environmental impact. The results showed that the addition of fly ash from Astana to polystyrene concrete leads to a marked reduction in thermal conductivity, contributing to improved energy efficiency of the building envelope. Optimal results were achieved by using 15% of Astana fly ash as an additive in polystyrene concrete, which led to a significant reduction in thermal conductivity of 51.47%. This reduction is in line with improving the energy efficiency of building materials, especially in cold climates.

Keywords: polystyrene concrete; thermal conductivity; fly ash; isolation material; cement composite



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1. Introduction

Concrete is a widely used building material, with its quality heavily reliant on the cement it contains. However, traditional cement production processes are both energy-intensive and environmentally damaging due to greenhouse gas emissions [1,2]. This necessitates the exploration of alternative materials that can replace some of the cement in

concrete without compromising its properties [3,4]. Fly ash, a byproduct of coal combustion from thermal power plants, is one such material that has gained attention [5,6]. It exhibits pozzolanic properties, reacting with calcium hydroxide in cement to enhance concrete's strength and durability. Moreover, the use of fly ash reduces the environmental impact associated with conventional cement production [7–9].

Depending on fly ash's characteristics and particle size, its addition to cement can have varied effects on the resulting material's properties [10,11]. Various methods for producing mixed cement incorporating fly ash and their influence on the mechanical properties of resulting composites have also been explored [12–14].

The grinding process applied to fly ash can significantly improve its pozzolanic activity, primarily by increasing its surface area [15,16]. Ultrafine fly ash particles, achieved by reducing their average size, exhibit enhanced reactivity, benefiting concrete strength and durability. Furthermore, fly ash can impact cement hydration, hardening, and product strength positively, while also reducing the heat generated during hydration, thereby reducing the risk of concrete cracking [17–19]. Additionally, it contributes to long-term concrete durability by decreasing permeability and influencing cement crystallization processes, which are pivotal in determining material strength and durability [20–22].

Considering the modern construction landscape's emphasis on energy efficiency and environmental sustainability, this study explores ways to enhance the energy efficiency of building materials [23,24]. Specifically, it investigates the incorporation of fly ash, a byproduct of energy generation from the Astana Combined Heat and Power Plants (CHPP), into polystyrene concrete, renowned for its thermal insulation properties. The objective is to align with the principles and goals of the ISO 50001 standard, promoting the development of effective energy management and conservation systems across various industries, including construction [25,26]. Requirements for the thermal conductivity of polystyrene concrete are necessary to ensure that the material meets certain standards of thermal performance. These requirements help determine the effectiveness of polystyrene concrete as an insulating material [27–29]. While no universal thermal conductivity requirements apply to all polystyrene concrete applications, they usually depend on the specific project, building codes, and standards of the region in which the material is used. The background for the research was usage of this fly ash in compositions as a substitute for a part of cement is economically favorable and ecologically feasible in connection with large accumulations of waste at the enterprises of the energy sector.

The main aim of this study is to develop compositions of polystyrene concrete with reduced thermal conductivity for building applications as a material with increased isolation properties. This article presents the data connected with the thermal properties of a new material polystyrene concrete with the addition of fly ash from Astana that was not investigated before. This fly ash is not used currently for this particular application. The main finding emphasizes the prospect of using fly ash as an energy-efficient building material under the requirements of ISO 50001 standards on energy management and energy conservation. The novelty of this article is connected with the application of waste materials as important admixtures for isolation composites.

2. Materials and Methods

2.1. Materials

The four basic ingredients have been applied for the preparation of polystyrene concrete (concrete, polystyrene, fly ash, and superplasticizer). The basic matrix material was Portland Cement M400 (produced by Kokshe-cement Limited Liability Partnership, Kokshetau, Kazakhstan). It plays the role of the binder in the composition. This cement has an initial setting time of 107 min and a final setting time of 260 min. The compressive strength after 28 days is above 40 Mpa, as shown in Table 1.

The elemental composition of Portland cement M400 is presented in Table 2.

Table 1. Characteristics of Portland cement used [2].

Cement	Setting Time, h-min		Bending Strength, MPa, in Days			Ultimate Compressive Strength, MPa, in Days		
	Start	End	3	7	28	3	7	28
Portland cement 400	1-47	4-20	2.67	3.5	4.22	20.7	30.12	41.0

Table 2. Chemical composition of used Portland cement [2].

	Chemical Composition, wt %								
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	Other Elements	Loss on Ignition	Sum
Portland cement	20.49	4.80	4.40	63.42	1.47	2.25	0.86	1.55	100.00

Portland cement “Kokshe-Cemend400”, like other Portland cements, contains clinker, which includes important minerals such as alite and belite. It also contains gypsum and mineral additives that improve the characteristics of the cement. The number 400 indicates the ability of the cement to withstand a load of 400 kg/cm², making it suitable for a variety of construction applications, especially where ultra-high strength properties are not required. Portland cement “Kokshe-Cemend400” has good compressive strength, and medium setting speed, which is useful for concrete work in moderate climatic conditions. It also has good frost resistance and resistance to aggressive environments. And it also is widely available and is value for money.

For the increasing thermal properties of the concrete polystyrene granules (EPS) of uniform type (Joint-stock Company “Sibur-Khimprom”, Moscow, Russian Federation) was applied. They have a density between 14 and 20 kg/m³ and granule sizes between 1.0 and 1.6 mm. The material has high purity (more than 99% according to supplier declaration).

As an admixture for improvement, a fresh properties superplasticizer MasterGlenium 116 (Master Builders Solution, Astana, Kazakhstan) was applied. The main goal of this superplasticizer was to enhance the mix’s workability. In the case of the provided experiment, the admixture was applied in 0.3% of the mixture’s weight. This superplasticizer is dedicated to the production of both ready-mix concrete and precast concrete. It works effectively in mixtures of any mobility class. The used admixture was added together with the mixing water (with the last third of the water). The recommended dosage is 0.4 to 2.0% of the weight of cement. The exact amount of the admixture was selected in the laboratory by trial mixing.

This study focuses on analyzing the impact of fly ash from Astana on the thermal conductivity of polystyrene concrete, utilizing a comprehensive approach that includes characterizing the fly ash, preparing the concrete mixtures, and conducting thermal conductivity tests. The detailed characteristic of the fly ash from Astana’s main power plant was the subject of provided research in this article. The delivered fly ash was processed in a ball mill for 2.4 h using 40 mm diameter grinding balls to achieve the desired fineness for further application in samples.

2.2. Preparation of Polystyrene Concrete Mixtures

In the first step, the compositions of polystyrene concrete were defined, using a standard GOST 27006-2019 [30]. Polystyrene concrete was chosen because, in Kazakhstan, there is a serious problem with the thermal insulation of buildings, especially with heat losses. Polystyrene concrete, due to its properties, allows to effectively combat this problem. An important advantage is that it incorporates fly ash waste from the thermal power plant of Astana city, which not only contributes to the improvement of thermal insulation, but also helps to utilize industrial waste. At the same time, the material retains sufficient compressive strength, which makes it suitable for use as a building envelope without compromising the overall reliability of buildings.

Polystyrene concrete has a lower density than conventional concrete, which makes it much lighter. Thanks to polystyrene foam granules, the material has high thermal insulation properties. It retains heat well and helps to reduce the heating costs of buildings. Polystyrene concrete also has excellent soundproofing properties, making it suitable for use in residential buildings. Despite the presence of polystyrene, polystyrene concrete is resistant to high temperatures and does not contribute to the spread of fire. Polystyrene concrete has sufficient strength for use in structural elements, but its strength characteristics are slightly lower compared to traditional concrete.

The compositions included Portland cement (M400), polystyrene foam balls (PPS), fly ash, water, and a superplasticizer additive. The mix proportions were experimentally determined, varying the amount of fly ash to replace part of the cement and comparing them with control mixes without fly ash, to optimize workability and compressive strength. Also, some trials corresponded with superplasticized admixture (Table 3).

Table 3. Samples compositions.

Samples	Cement (%)	Polystyrene (vol. %)	Ash (%)	Superplasticizer (%)	Water (mL)
REF-PC	100	60	-	-	660
PC5FA	95	60	5	-	660
PC10FA	90	60	10	-	660
PC15FA	85	60	15	-	660
PC5FASP	95	60	5	0.30	660
PC10FASP	90	60	10	0.30	660
PC15FASP	85	60	15	0.30	660

The mixing process involved pre-mixing dry components (cement, fly ash, sand, polystyrene granulates) for uniformity, followed by the addition of water and superplasticizer, and thorough mixing to achieve a homogeneous consistency.

The percentages of 5%, 10%, and 15% fly ash addition were chosen based on the need to achieve an optimum balance between the strength and thermal insulation properties of polystyrene concrete. The introduction of 5% fly ash allows for the evaluation of the effect of a minimum amount of additive on the material structure, providing a basic level of modification without significant changes in density and strength. Increasing to 10% allows us to study how increasing the fly ash content affects the improvement of thermal insulation properties and the filling of microvoids, which contributes to a more uniform load distribution. The 15% addition was chosen to determine the upper limit of fly ash efficiency at which the maximum effect of fly ash incorporation can be achieved without significant deterioration in the mechanical properties of the material. This range of concentrations provides extensive data for the analysis and optimization of polystyrene concrete depending on the required performance characteristics. The study of samples containing 5%, 10%, and 15% fly ash provides an opportunity to identify the most effective ratio, which maximizes the improvement of thermal insulation properties without a significant reduction in compressive strength. This is important to ensure the durability and reliability of structures in which polystyrene concrete will be used, especially in climatic conditions typical for Kazakhstan, where the issue of heat preservation in buildings is of paramount importance.

The amount of added water was connected with necessary to obtain proper workability of the concrete paste. The changes in other ingredients were part of the planned experiment.

Specimens for thermal conductivity tests were molded into cubic and cylindrical shapes and cured under controlled conditions.

The overall flowchart for investigation is presented in Figure 1.

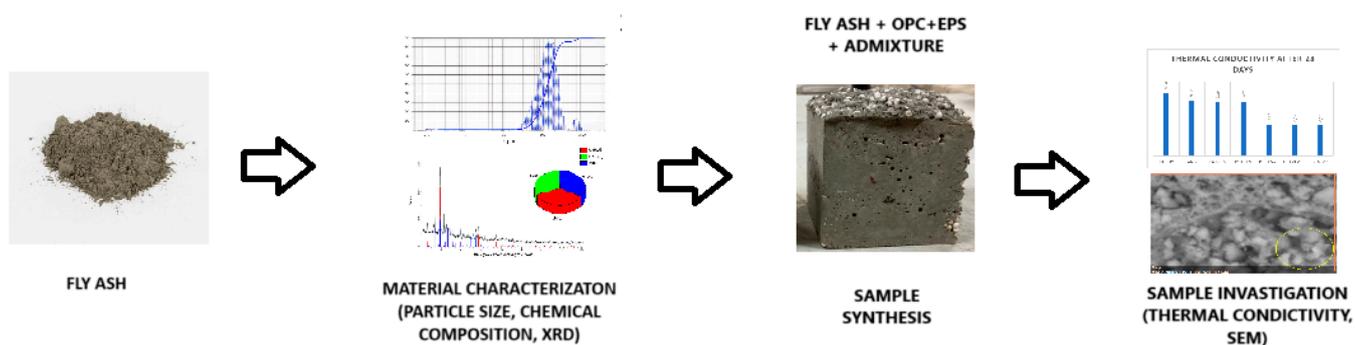


Figure 1. Flowchart for provided research.

2.3. Research Methods

Particle Size Analysis was provided on a laser particle size analyzer (FRITSCH Analysette 22 (FRITSCH GmbH, Idar-Oberstein, Germany), laser method). It was determined according to ISO 13320 using the wet method. Chemical composition was assessed using X-ray fluorescence spectroscopy with a D8 ADVANCE ESO diffractometer. Mineralogical composition—X-ray phase analysis (XRD) was conducted using a D8 ADVANCE ESO diffractometer, which employed radiation from an X-ray tube with a copper anode and a graphite monochromator on the diffracted beam. Diffractograms were captured over a 2θ angle range of 15–100 degrees, with a step size of 0.02 degrees 2θ . For phase identification and the study of crystal structures, Bruker AXS DIFFRAC.EVA version 4.2 software alongside the international databases ICDD PDF-2 and COD were utilized.

The thermal conductivity of the polystyrene concrete samples was measured using the ITP-MG4 instrument (Zapadpribor, Lviv, Ukraine), according to the GOST 7076 standard [31]. This method is suitable for materials with low-to-medium thermal conductivity, enabling the determination of both thermal conductivity and resistance at average specimen temperatures ranging from +15 to +42.5 °C, with automatic temperature control of the cooling and heating systems during testing. Before the test, the samples were dried to a constant mass. The test results were then analyzed. The integrated approach of material characterization, concrete preparation, and standardized testing procedures aims to provide a reliable evaluation of how Astana's fly ash influences the thermal conductivity of polystyrene concrete. The tests were conducted on a minimum of 3 samples.

3. Results

3.1. Characterization of Astana Fly Ash

Physicochemical characterization of Astana fly ash revealed the main properties connected with particle size distribution advantages for application in building materials. The ash had predominantly fine particle size distribution, a significant part of which was in the micron range. The composition of ash according to particle size (fractions) is presented in Figure 2.

Three different samples from various places have been characterized. Sample 1 is characterized by a large number of particles ranging in size from 10 to 50 microns, and sample 2 is less than 100 microns. Sample 3 is a mixture of fly ash and larger ash fractions.

Also, the chemical composition of the fly ash has been tested. The results are given in Table 4.

The main elements in the composition are aluminum and silica. These elements are typical for building materials. Fly ash also contains quite a large amount of ferrum and calcium. Because of the existence of a large number of ferrum, the additional process of this element recovery can be considered in the case of the application of this material on a wider scale. The amount of elements that are potentially hazardous is an acceptable level; however, further leaching tests on the ready products should be considered.

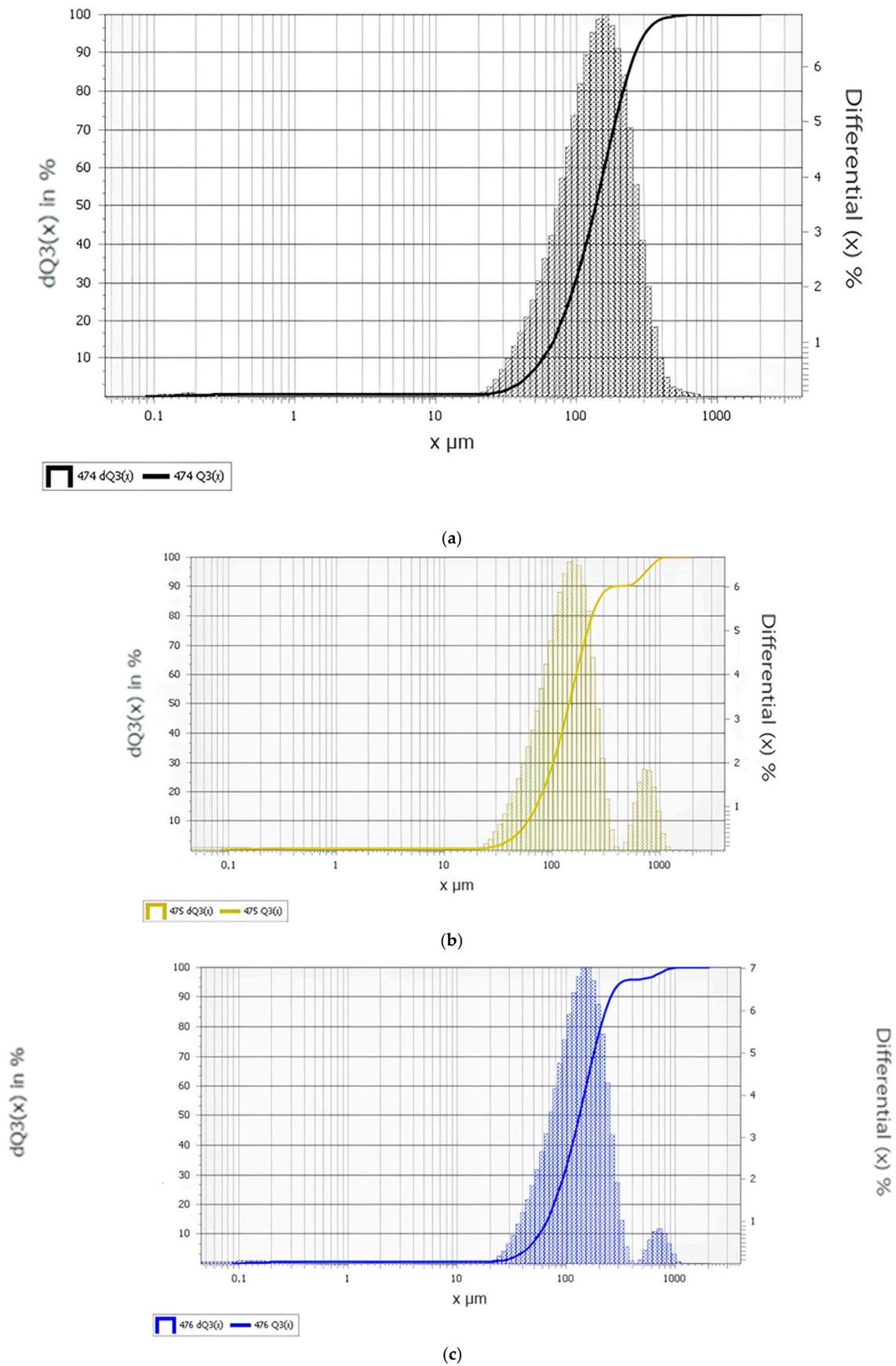


Figure 2. Particle size distribution: (a) fly ash sample; (b) ash samples from ash dump; (c) ash samples from hydraulic ash dump.

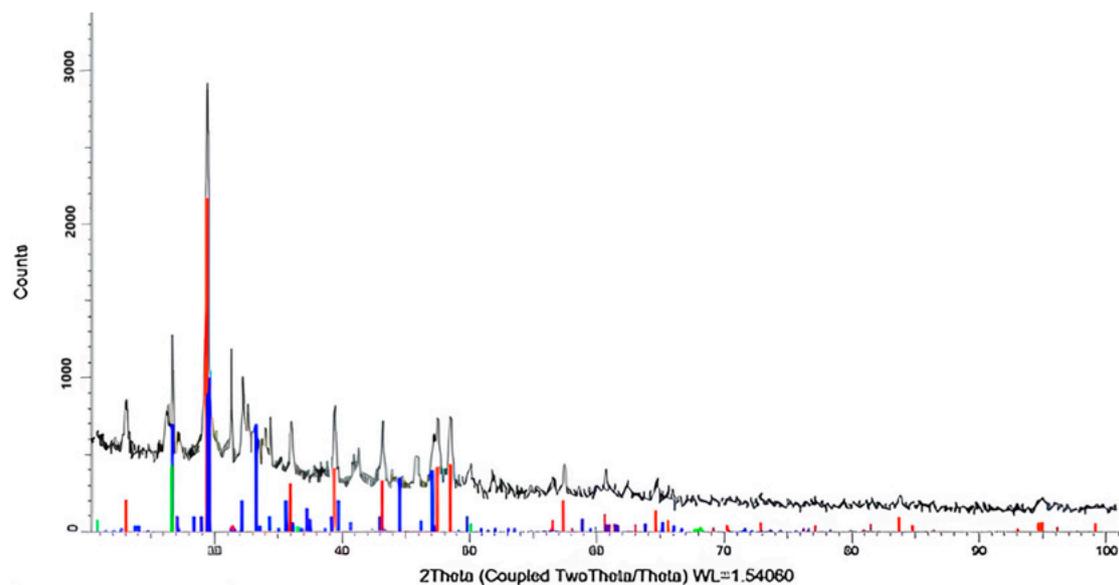
Table 4. Elemental composition of fly ash from Astana CHPP.

No.	Item	Sample 1	Sample 2	Sample 3	No.	Item	Sample 1	Sample 2	Sample 3
1	Al	17.346	19.755	19.608	17	Rb	0.012	0.014	0.015
2	Si	40.919	50.989	52.327	18	Sr	0.236	0.230	0.237
3	P	0.610	0.695	0.717	19	y	0.025	0.025	0.025
4	S	0.199	0.091	0.079	20	Zr	0.140	0.155	0.166
5	Cl	0.126	0.171	0.172	21	Nb	0.006	0.006	0.006
6	K	1.629	2.094	2.207	22	STi	0.028	0.026	0.025
7	Ca	9.926	4.155	3.350	23	Te	0.018	0.021	0.017
8	Ti	2.847	2.998	3.170	24	Ba	0.287	0.251	0.254
9	V	0.059	0.055	0.060	25	Eu	0.162	0.120	0.115
10	Mn	0.405	0.321	0.303	26	Yb	0.017	0.015	0.016
11	Fe	24.916	17.659	16.999	27	Re	0.000	0.000	0.000
12	Ni	0.001	0.004	---	28	Os	0.000	0.000	0.000
13	Si	0.045	0.053	0.051	29	Ir	0.000	0.000	0.000
14	Zn	0.018	0.069	0.032	30	Pb	0.004	0.008	0.009
15	Ga	0.013	0.013	0.014	31	Nd	---	0.002	0.002
16	As	0.004	0.004	0.004	32	Lu	---	---	0.014

Supplementary to chemical composition, mineralogical composition was also investigated by X-ray phase analysis. The results are presented in Figures 3 and 4 as well as Table 5.

Table 5. Structural parameters were determined during the analysis of the main phases.

No	Name of Phase	Type of Structure	Crystal Lattice Parameters, Å
1	Ca(CO) ₃ —PDF-00-042-1455	Rhombo.H.axes	a = 5.00366, c = 17.19992, V = 372.93 Å ³
2	Ca ₂ SiO ₃ Cl ₂ —PDF-00-042-1455	Orthorhombic	a = 12.63558, b = 15.69570, c = 7.74071, V = 1535.17 Å ³
3	SiO ₂ —PDF-01-070-7344	Hexagonal	a = 4.94838, c = 5.40751, V = 114.67 Å ³

**Figure 3.** X-ray diffraction results of fly ash with phase decoding were obtained by analyzing the position of the main diffraction reflexes and their coincidence with card values from the PDF-2 database.

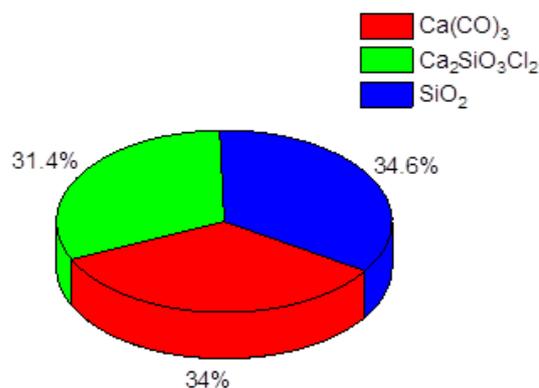


Figure 4. Phase composition of fly ash.

Table 5 presents the data on the structural parameters of the main phases determined during the analysis. The degree of crystallinity of fly ash was 77.1%.

The XRD analysis revealed a large amount of calcium compounds that can be supportive for creating bonding in concrete. Quartz usually positively influences the mechanical properties of the building materials [4,32].

3.2. Characterization of Polyester–Concrete Mixtures

The part of the prepared specimen with the addition of fly ash and superplasticizer is shown in Figure 5.

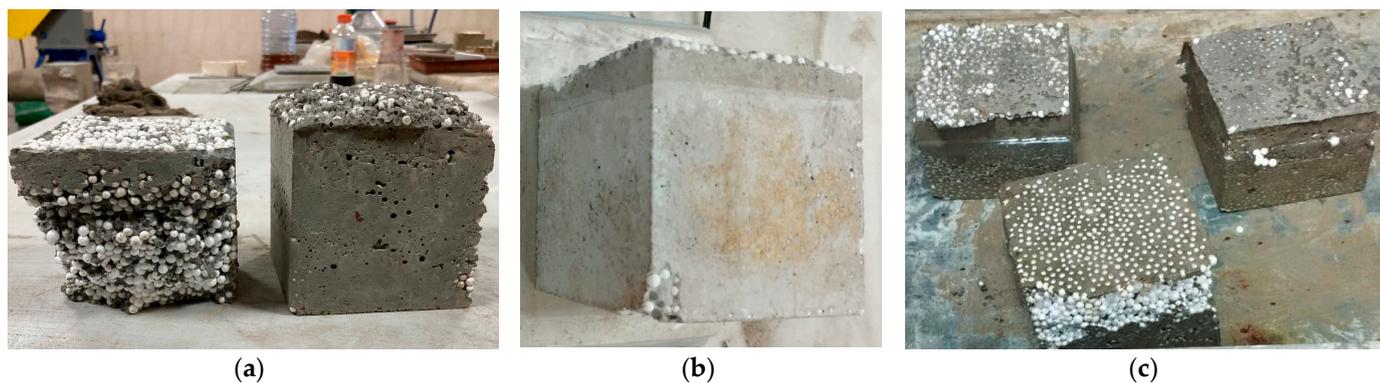


Figure 5. Prepared samples of polystyrene concrete: (a) polystyrene concrete outside and inside, (b) polystyrene concrete outside, (c) samples during preliminary research.

The results for the thermal conductivity are presented in Figures 6–8.

As the proportion of fly ash used as a replacement aggregate increased, there was a decrease in thermal conductivity compared to the control specimen. The minimum thermal conductivity values were recorded for the specimen with the addition of 15% of the fly ash and plasticizer. The thermal conductivity for the fresh samples was worse than after the curing process. It was probably caused by internal water bonded in the material.

The results indicate that the thermal conductivity values for all concrete samples with polystyrene and fly ash are lower than those of the control concrete specimen. The maximum thermal conductivity was found in the control specimen, which contained neither fly ash nor superplasticizer. The specimen with a composition of 60% polystyrene and 15% fly ash exhibited the most favorable thermal conductivity value when compared to the control, showing a reduction in thermal conductivity of 51.47%.

This study indicates that thermal conductivity diminishes as the amount of polystyrene foam and superplasticizer is increased. This reduction in thermal conductivity can be attributed to the composition of closed-cell EPS, which is 98% air and the remainder polystyrene. In this case, the porosity of the materials also plays an important role in

thermal isolation. Additionally, the superplasticizer's capacity to absorb water and expand within 48 h of water introduction plays a role. Over the 28-day drying period, the samples undergo water loss within their structure, leading to the creation of artificial micropores outside the polystyrene foam's pores within the cement matrix of the material.

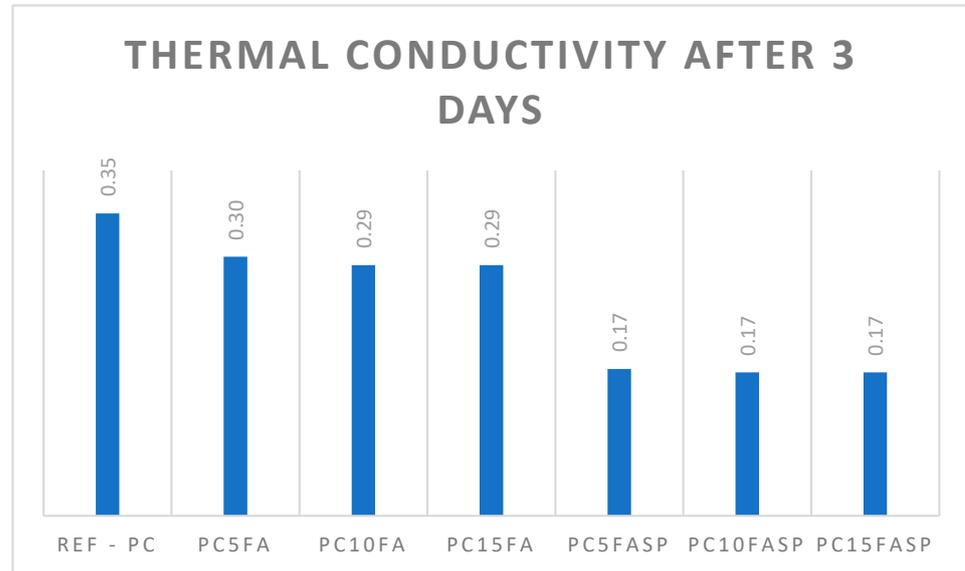


Figure 6. Thermal conductivity after 3 days.

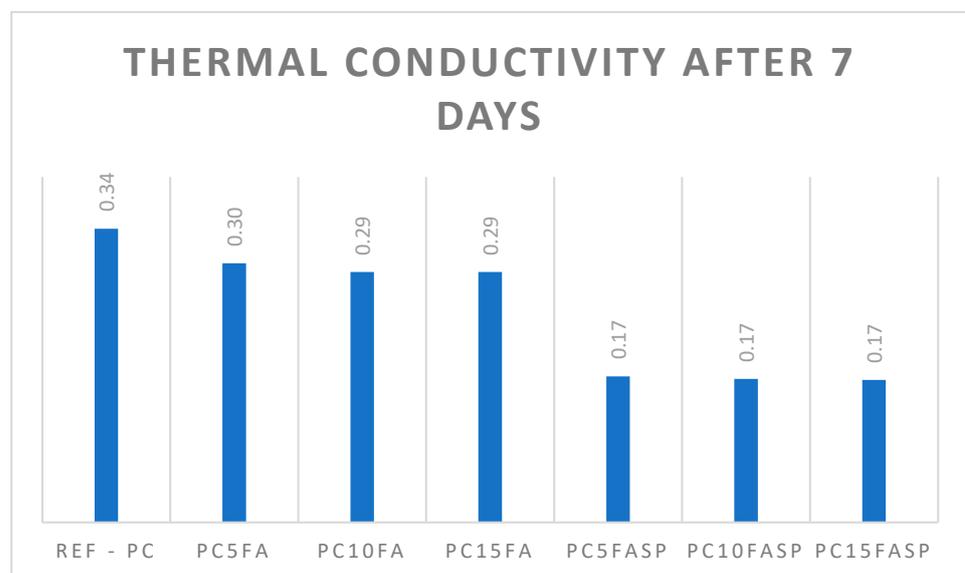


Figure 7. Thermal conductivity after 7 days.

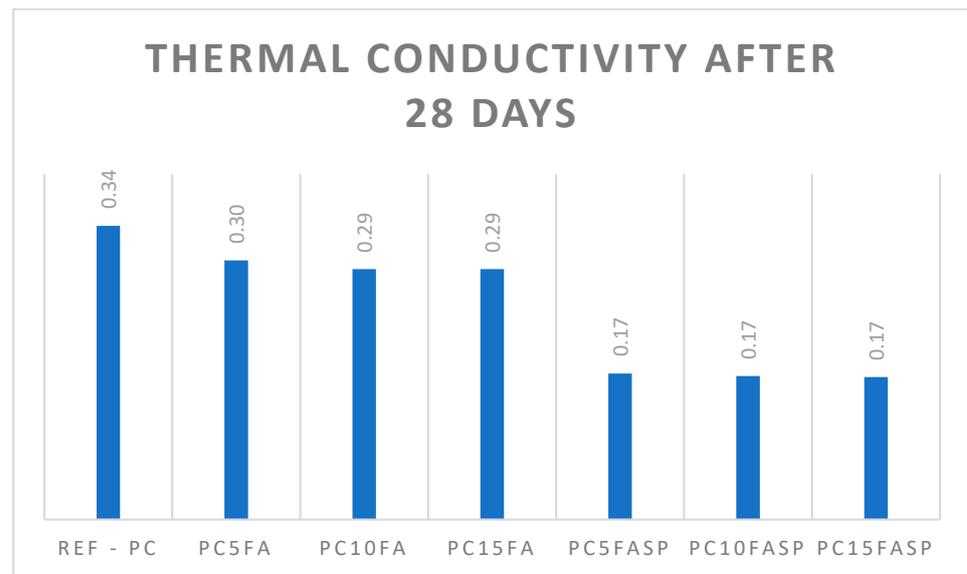


Figure 8. Thermal conductivity after 28 days.

Additionally, to confirm a better understanding of the mechanism the microscopic observation was provided. The main results are presented in Figure 9. The cured samples reveal that ash particles rich in aluminates aid in the creation of calcium hydro-sulfo-aluminates and actively adhere to the particle surfaces.

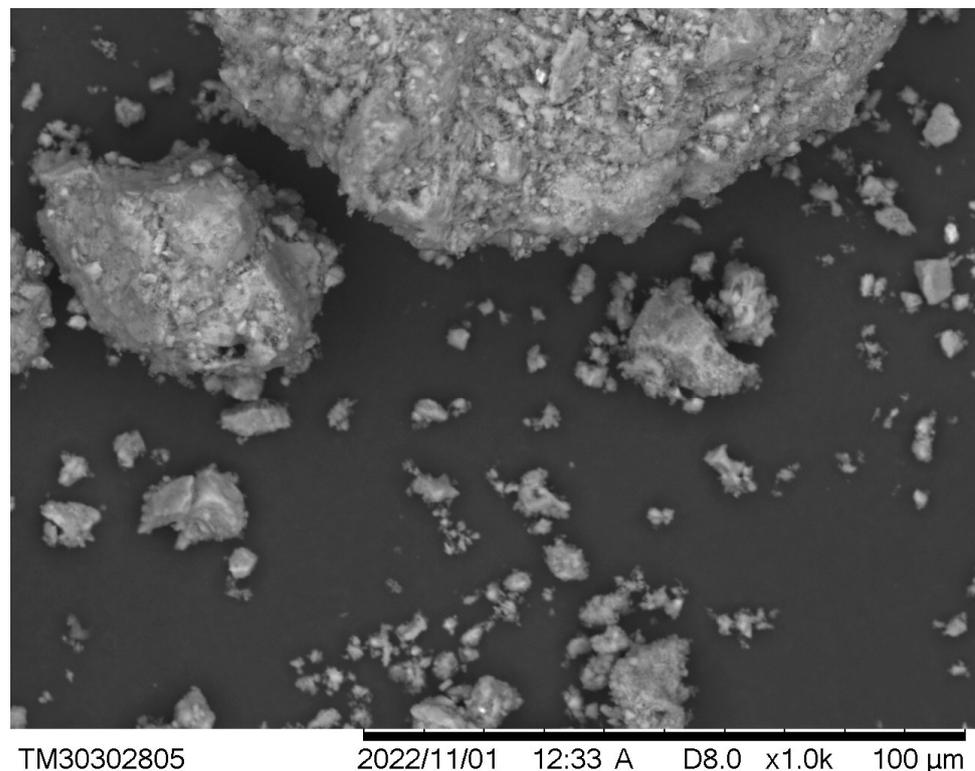


Figure 9. Microphotographs of quenched specimens without additives after 28 days of curing, $\times 1000$.

The obtained data clearly demonstrate that the inclusion of Astana fly ash has a significant effect on the thermal conductivity of polystyrene concrete. When the percentage of fly ash in the mix increases, a marked decrease in thermal conductivity is observed. This trend is in agreement with the results of previous studies on the pozzolanic effect

of fly ash, in which amorphous silica contained in fly ash acts as a heat insulator in the concrete matrix.

The results obtained are in agreement with previous studies on the effect of fly ash on the thermal properties of concrete. The observed reduction in thermal conductivity is consistent with the insulating properties inherent in fly ash particles. This is in line with the objectives of the ISO 50001 standard to use materials that improve energy efficiency. The previous study also indicates that as the proportion of fly ash in polystyrene concrete increases, there is a marked reduction in strength. The higher the fly ash content, the more significant the reduction in the strength of the material becomes, which emphasizes the effect of fly ash on the structural integrity of polystyrene concrete [2].

The results of this study are of twofold significance. Firstly, fly ash from the thermal power plant of Astana is a valuable additive for improving the energy efficiency of polystyrene concrete, which is consistent with the requirements of the ISO 50001 standard on energy management and energy conservation in building materials. Secondly, this study contributes to sustainable development by utilizing locally produced waste, reducing landfill waste, and reducing the environmental footprint of construction.

The limitations of this study need to be recognized. Although the reduction in thermal conductivity is favorable for energy-efficient construction, the potential effects on other mechanical properties such as compressive strength require further investigation. In addition, the long-term performance and durability of polystyrene concrete modified with Astana fly ash need to be investigated under real application conditions.

In the results of this study, it should be noted that the inclusion of Astana fly ash in polystyrene concrete significantly reduces its thermal conductivity, which makes it a promising material for improving the energy efficiency of buildings. This study contributes to the achievement of sustainable development goals of the construction industry and compliance with the principles of ISO 50001 standard, offering an effective strategy to improve the thermal performance of building materials while reducing waste and environmental impact.

4. Discussion

Building codes and standards, which vary by country and region, often specify maximum thermal conductivity values for insulation materials, including polystyrene concrete. For example, in Kazakhstan, the standard SNiP-RK-5.03-34-2005 sets the thermal conductivity limits in Table 6. Compliance with these norms and standards is crucial to ensure that polystyrene concrete meets the minimum thermal performance requirements [33].

Table 6. Standardized values of heat transfer resistance of envelope structures.

Buildings and Premises, Coefficients <i>a</i> and <i>b</i>	Degree-Days of the Heating Period, Dd °C-day	Standard Values of Heat Transfer Resistance, R_{req} m ² ·°C/W, of Envelope Structures				
		Walls	Floors and Slabs over Passages	Attic Ceilings, over Unheated Cellars and Basements	Windows and Balcony Doors, Shop Windows, and Stained Glass Windows	Lanterns with Vertical Glazing
1	2	3	4	5	6	7
1. Residential, medical preventive, and child care institutions, schools, boarding schools, hotels, and dormitories	2000	2.1	3.2	2.8	0.3	0.3
	4000	2.8	4.2	3.7	0.45	0.35
	6000	3.5	5.2	4.6	0.6	0.4
	8000	4.2	6.2	5.5	0.7	0.45
	10,000	4.9	7.2	6.4	0.75	0.5
	12,000	5.6	8.2	7.3	0.8	0.55
<i>a</i>	-	0.00035	0.0005	0.00045	-	0.000025
<i>b</i>	-	1.4	2.2	1.9	-	0.25
2. Public, other than those mentioned above, administrative and domestic, industrial, and other buildings and premises with damp or wet conditions	2000	1.8	2.4	2.0	0.3	0.3
	4000	2.4	3.2	2.7	0.4	0.35
	6000	3.0	4.0	3.4	0.5	0.4
	8000	3.6	4.8	4.1	0.6	0.45
	10,000	4.2	5.6	4.8	0.7	0.5
	12,000	4.8	6.4	5.5	0.8	0.55
<i>a</i>	-	0.0003	0.0004	0.00035	0.00005	0.000025
<i>b</i>	-	1.2	1.6	1.3	0.2	0.25
3. Production facilities with dry and normal conditions	2000	1.4	2.0	1.4	0.25	0.2
	4000	1.8	2.5	1.8	0.3	0.25
	6000	2.2	3.0	2.2	0.35	0.3
	8000	2.6	3.5	2.6	0.4	0.35
	10,000	3.0	4.0	3.0	0.45	0.4
	12,000	3.4	4.5	3.4	0.5	0.45
<i>a</i>	-	0.0002	0.00025	0.0002	0.000025	0.000025
<i>b</i>	-	1.0	1.5	1.0	0.2	0.15

Notes:

1. Values R_{req} for the values D_d , differing from the tabulated values should be determined by the following formula:

$$R_{req} = a \cdot D_d + b \quad (1)$$

where D_d —degree days of the heating period, °C·day—item specific; a , b —coefficients, the values of which should be taken according to the table for the corresponding groups of buildings, except for column 6 for the group of buildings in pos. 1, where for the interval up to 6000 °C·day: $a = 0.000075$, $b = 0.15$; for the interval 6000–8000 °C·day: $a = 0.00005$, $b = 0.3$; for the interval 8000 °C·day and more: $a = 0.000025$, $b = 0.5$.

2. The standardized reduced heat transfer resistance of the blind part of balcony doors should be at least 1.5 times higher than the standardized heat transfer resistance of the translucent part of these structures.

3. The standardized values of the heat transfer resistance of attic and basement ceilings separating the building premises from unheated spaces with temperature t_c ($t_{ext} < t_c < t_{int}$), should be reduced by multiplying the values specified in column 5 by the coefficient n determined according to the note to Table 6. In this case, the design air temperature in the warm attic, warm basement, and glazed loggia and balcony should be determined on the basis of heat balance calculation.

4. It is allowed to use window, balcony door, and skylight constructions with reduced heat transfer resistance 5% lower than that specified in the table in individual cases related to specific design solutions of window and other openings.

5. For the group of buildings in pos. 1, the standardized value of heat transfer resistance of the floor slabs above the stairwell and the warm attic, as well as above the passages, if the floor slabs are the floor of the technical story, should be taken as for the group of buildings in item 2.

The important is also the repetitiveness of the obtained results. Thermal conductivity requirements may vary depending on the climate zone in which the building is located. Colder climates such as Astana usually have more stringent thermal insulation requirements than milder or warmer regions. Therefore, the thermal conductivity of polystyrene concrete used in cold climates should be lower to provide better thermal insulation and reduce heat loss [34,35].

Thus, the thermal conductivity requirements for polystyrene concrete significantly depend on project specifics, building codes, climate zones, and sustainability goals. It is essential to carefully consider these factors at the manufacturing stage and ensure that the polystyrene concrete material selected meets the required thermal conductivity standards. In addition, local building codes and standards must be followed to ensure that the thermal insulation properties of polystyrene concrete meet regulatory requirements.

In regions with cold climates, the efficient utilization of heat in buildings is of paramount importance. High heating demands during long winters place a significant strain on energy resources and contribute to increased greenhouse gas emissions. To address this problem, researchers and practitioners are constantly looking for innovative solutions to improve the energy efficiency of building materials and minimize heat loss. This study considers the possibility of incorporating fly ash, which is a by-product of thermal energy production, into polystyrene concrete, a material known for its thermal insulation properties. In doing so, the aim is to mitigate the problems associated with thermal conductivity in cold countries.

Cold countries face a unique set of challenges in the construction and operation of energy-efficient buildings. One of the main challenges is heat conduction, where heat is lost through building materials due to their inherent thermal conductivity. In extremely cold weather conditions, this heat loss requires increased heating effort, resulting in increased energy use and associated costs. In addition, the environmental impacts of intensive energy use are exacerbating the challenges associated with climate change [36,37].

Polystyrene concrete is a promising solution to the problem of thermal conductivity. It is a composite material that includes polystyrene foam balls in the cement matrix. The

inclusion of these beads in the cement matrix provides insulating properties, making polystyrene concrete an excellent choice for construction in cold climates. Its ability to reduce heat transfer helps to maintain a comfortable indoor temperature and minimize energy consumption.

Fly ash, which is a residue from the combustion of coal in thermal power plants, has significant potential to further enhance the thermal insulation properties of polystyrene concrete. This material is rich in amorphous silica, which has low thermal conductivity. When incorporated into the concrete mix, fly ash acts as a thermal insulator in the matrix of the material. This phenomenon is attributed to the lower thermal conductivity of fly ash particles compared to conventional building materials, which enables it to inhibit heat transfer through concrete [38,39].

In light of these considerations, this study suggests that the incorporation of fly ash from thermal power plants into polystyrene concrete can effectively reduce the thermal conductivity of polystyrene concrete. This will solve the problem of thermal conductivity in cold countries and at the same time promote the development of environmentally friendly construction [40–42]. The results also show that these admixtures improve the coherence of the materials, which provides a potential possibility to investigate them in other fields of applications [43,44].

However, the obtained results are promising the designed materials required further studies. The most important element is to consider the long-term effects of fly ash application, for example, in the context of material degradation under natural conditions. This kind of test requires a long-term study, including investigations of climatic chambers [45,46]. In this case, some computer modeling can also be useful to predict possible phenomena [47].

Another important limitation is connected to the application of fly ash as a raw material. This kind of material is usually characterized by significant changeable during the year as well as other factors [48,49]. This fact can influence material properties, including mechanical properties. An important factor can be also a long-term perspective can be a tendency to change the energy sources from fossil fuels to renewable ones [50,51]. It will cause a shortage of fly ash in the future [51,52]. Despite this fact, at the current moment, the usage of fly ash seems to be an environmentally valid opportunity for up-cycling this kind of waste.

5. Conclusions

In this work, the influence of the inclusion of fly ash from Astana CHPP in polystyrene concrete and its effect on thermal conductivity was investigated. The objectives of this study were to determine the characteristics of fly ash from Astana CHPP, formulate polystyrene concrete mixtures with different percentages of fly ash, evaluate their thermal conductivity, and harmonize the results with ISO 50001 principles of energy management.

The incorporation of fly ash from Astana in polystyrene concrete resulted in a significant reduction in thermal conductivity up to 51.47% for mixtures with 15% of fly ash. With an increasing percentage of fly ash content, the thermal conductivity decreased, which is consistent with the insulating properties of fly ash particles. This result indicates the possibility of using Astana fly ash to improve the energy efficiency of polystyrene concrete.

The results of this study have broad implications for the construction industry and sustainable development efforts:

- **Energy efficiency:** The reduced thermal conductivity of polystyrene concrete with fly ash from Astana is in line with the global drive for energy-efficient building materials. Reduced thermal conductivity results in lower energy consumption for heating and cooling, which contributes to sustainable buildings.
- **Waste management:** By using local waste, this study supports sustainable waste management practices and reduces the environmental burden associated with landfill disposal of fly ash.
- **Practical implications:** The practical implications of this study extend to the construction industry in Astana and beyond.

- Utilization of local resources: The availability of fly ash in Astana as an additive in building materials offers a cost-effective and sustainable solution to improve the thermal performance of buildings in the region. This is in line with regional sustainability and energy efficiency goals.
- Energy savings: When polystyrene concrete modified with Astana fly ash is used in construction projects, builders and developers can benefit from reduced energy costs associated with heating and cooling.

In conclusion, this study highlights the potential of fly ash from Astana as a valuable additive for improving the thermal insulation properties of polystyrene concrete. By reducing thermal conductivity, this local waste fulfills the principles of the ISO 50001 energy management standard and contributes to sustainable construction in the Astana region and beyond. This emphasizes the importance of using local resources to create energy-efficient building materials and reduce environmental impact.

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