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Rheological Properties of Asphalt Concrete based on Asphalt-resin and Paraffin Deposits of Oil Fields and Ash of Thermal Energy Central of Kazakhstan

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Abstract The research is devoted to the study of the possibility of using asphalt resin-paraffin residues and ash from thermal power plants in the production of asphalt concrete to improve its performance and reduce environmental impact. The study employed samples of asphalt-resin-paraffin deposits from oil fields in the Kyzylorda region, infrared spectroscopy and gas chromatography-mass spectrometry to determine the specific surface area and activity of natural radionuclides in the ash from the Kyzylorda thermal power plant. The main results of the study show that fly ash from thermal power plants contains a high content of silicon oxide (30.03-62.53%) and aluminium oxide (8.84-30.92%). Spectral analysis of asphalt-resin-paraffin residues from oil fields revealed the presence of hydrocarbons in methyl and methylene groups. The optimum composition of the composite binder “Bitumen – asphalt resin-paraffin residues – thermal power plant ash” is as follows: bitumen – 80-82%, thermal power plant ash – 7-11%, asphalt resin-paraffin residues – 8.5-9.5%. The resulting asphalt concrete demonstrated high compressive strength (2.2-2.5 MPa at 50 ℃, 4.4-5.2 MPa at 20 ℃, 9.7-9.9 MPa at 0 ℃), high shear stability (internal friction coefficient 0.85-0.87), excellent shear adhesion at 50 ℃ (0.62-0.86), high water resistance (0.89-0.98) and low water saturation (1.22-2.2%). The results also show that the use of thermal power plant ash and asphalt resin-paraffin residues in asphalt concrete improves its performance and reduces the environmental impact through waste recycling. The data obtained confirm the possibility of effective use of these materials in road construction in Central Kazakhstan. This research brings to science a practical methodology for developing asphalt concrete composition using asphalt resin-paraffin residues and ash from thermal power plants, which contributes to the efficient use of resources and reduction of environmental impact in road construction.

Keywords Road Surface, Ash from Thermal Power Plants, Tensile Strength, Water Resistance, Paraffin Deposits

1. Introduction

The rheological properties of asphalt concrete are a key factor in determining its performance and durability. In Central Kazakhstan, interest in the use of local natural and anthropogenic resources in the construction of road surfaces has increased [1]. Asphalt resin-paraffin residues

(ARPR) from oil fields and ash from thermal power plants (TPPs) are promising components for the production of asphalt concrete. The use of these materials not only improves the properties of asphalt concrete but also solves the problem of industrial waste disposal, which is an important environmental aspect. The need to conduct this study is due to the current problems of the use and disposal of ARPR and ash from thermal power plants in Central Kazakhstan. Oilfield ash and TPP ash pose a significant environmental threat due to the accumulation of waste and its negative impact on the environment and human health [2]. At the same time, these materials have the potential to improve the performance of asphalt concrete.

One of the key aspects of the impact of ash on the properties of asphalt concrete is its ability to effectively fill the pores in the asphalt concrete structure [3]. Due to its fine structure, fly ash improves the density of the mixture, which in turn increases its strength and resistance to various influences. Another important aspect is the improvement of the adhesive properties of asphalt concrete under the influence of ash. This material promotes a tighter bond between bitumen and aggregates, which increases the adhesion and resistance of asphalt concrete to fracture. In addition, fly ash helps to increase the frost resistance and durability of asphalt concrete. Its presence in the mixture structure prevents the formation of microcracks and helps to maintain the integrity of the asphalt pavement even under extreme temperature fluctuations, such as those typical for the climate of Central Kazakhstan. In this region, where climatic factors can vary, the use of asphalt concrete based on thermal power plant ash is a promising solution. These mixtures have increased wear and heat resistance, making them an ideal choice for road construction in this region. The use of local materials, such as thermal power plant ash, in addition to increasing the economic efficiency of projects, contributes to improving the environmental situation by recycling energy production waste [4]. This reduces dependence on imported materials and contributes to the sustainable development of the region.

Researchers are actively studying the possibilities of using asphalt resin-paraffin residues and ash from thermal power plants in the production of asphalt concrete. G.M. Duarte and A.L. Faxina [5] determined that the addition of ASMA significantly improves the viscosity and plasticity of asphalt mixtures, which increases their resistance to deformation at high temperatures. S.R. Harnaeni et al. [6] noted that TPP ash contributes to better filling of pores in asphalt concrete, increasing its density and strength. A. Zia and A.A. Khan [7] demonstrated that fly ash improves the adhesive properties of asphalt concrete by increasing the adhesion between bitumen and aggregates. G. Girskas et al. [8] concluded that the use of thermal power plant ash in asphalt concrete improves its frost resistance and durability, which is especially important for regions with sharp temperature changes. H. Wu et al. [9] studied the chemical composition of ash and found a high content of silicon oxide and aluminium oxide, which has a positive effect on the properties of asphalt concrete.

A.M. Memon et al. [10] carried out a spectral analysis of the ARPR and revealed the presence of hydrocarbons in methyl and methylene groups, which allows for improving the rheological properties of the mixture. R. Polo-Mendoza et al. [11] used mathematical modelling to determine the optimal composition of asphalt concrete with the addition of ASMA and TPP ash, achieving significant improvements in strength and shear resistance. P. Cong et al. [12] confirmed that asphalt concrete mixtures have high water resistance and low water saturation, which increases their durability in conditions of high humidity. G.O. Bamigboye et al. [13] emphasised that the use of ARPR and TPP ash in road construction helps to reduce the environmental burden by recycling industrial waste and improving the environmental situation in the region.

Lastly, K. Bisenov et al. [14] substantiated the effects of asphalt resin-paraffin residue on asphalt concrete technology. These studies emphasise the importance of an integrated approach to the use of local natural and anthropogenic resources, which not only improves the properties of asphalt concrete but also solves current environmental problems. Despite the significant achievements, there are still several gaps that require further study. It is necessary to conduct more detailed research on the long-term stability of asphalt concrete with the addition of ARPR and TPP ash in service conditions, as well as to study the impact of different types of ash and ARPR on environmental safety and economic efficiency of asphalt concrete production.

The authors' investigation introduces a novel approach to asphalt concrete formulation by incorporating industrial by-products, specifically thermal power plant ash and asphalt-resin-paraffin deposits, which differentiates it from previous studies that primarily focused on traditional materials. This innovative method not only enhances the mechanical properties and durability of the asphalt concrete but also promotes sustainability through effective waste recycling. The work closes important gaps in the literature on the use of alternative materials in road construction by addressing the performance constraints of traditional asphalt mixtures. Furthermore, the research provides comprehensive insights into the synergistic effects of these additives on the rheological and mechanical characteristics of asphalt, thereby contributing to the development of more resilient and environmentally friendly pavement solutions.

The study aims to create asphalt concrete using asphalt-resin-paraffin deposits from oil fields and ash from thermal power plants. The objectives of the study were:

1. To study the physical and chemical properties of asphalt-resin-paraffin deposits and ash from thermal power plants used as components to produce asphalt concrete.
2. To determine the optimal composition of asphalt concrete mixtures with the addition of asphalt

resin-paraffin deposits and TPP ash using mathematical methods of experiment planning.

3. To evaluate the physical and mechanical properties of the resulting asphalt concrete, including strength, shear resistance, water resistance and durability, and in-service conditions.

The research is aimed at developing new, environmentally friendly and cost-effective technologies in road pavement construction, which will not only reduce the environmental burden but also improve the quality and durability of roads in the region.

2. Materials and Methods

At the beginning of the research, the raw materials to be used in the experiments to create asphalt concrete were thoroughly studied. This stage included an analysis of the chemical composition, physical properties and potential suitability of each component to achieve the required asphalt mix characteristics. The mathematical method of experiment planning was used to determine the most suitable asphalt composition. This approach was used to systematically change the values of various variables, such as the ratio of the mixture components, and analyse their impact on the final product characteristics to optimise its properties.

Many experiments were conducted to determine the physical and mechanical properties of the resulting asphalt concrete. These studies included an analysis of the compressive strength of the material at different temperatures, a study of its shear stability by the coefficient of internal friction and shear adhesion, as well as an assessment of water resistance and water saturation. In the experimental work, samples of ARPR obtained from the Kumkol and Kyzylkiya oil fields located in the Kyzylorda region were used (Figure 1). These samples were carefully selected for comprehensive analysis and experiments aimed at studying their properties and the possibility of using them in the production of asphalt concrete.

Figure 1. ARPR samples from the Kumkol field

The infrared (IR) absorption spectra of asphalt resin residues show characteristic bands indicating the presence of various hydrocarbon structures (Figure 2). In particular, the absorption bands corresponding to methyl groups at 2954-2840 cm-1, methylene groups at 1455-1360 cm-1, and methyl groups at 705 cm-1 are observed. These spectral data indicate a complex structure of hydrocarbon components in the ARPR. To confirm and complement these results, as well as to analyse the chemical composition of the ARPR in detail, gas chromatography combined with mass spectrometry was used on Agilent 7890N/5975 equipment. These experiments were used to obtain more precise data on the molecular structure and composition of the samples under study.

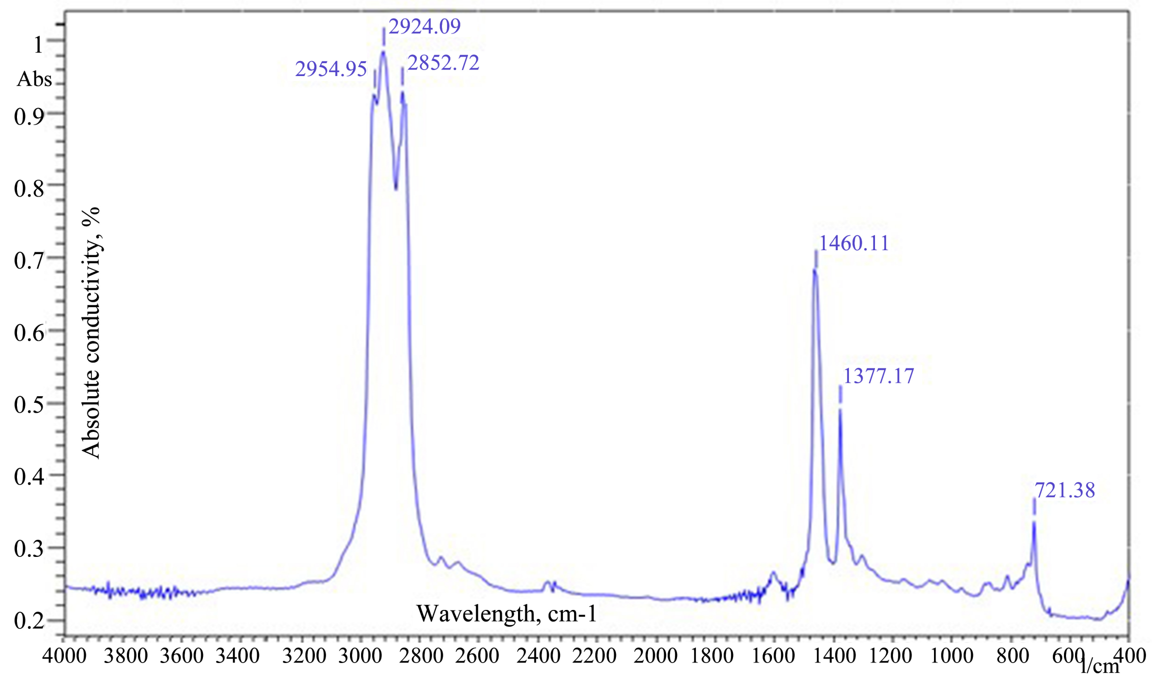

Figure 2. Infrared spectrum of the Kumkol field

The optimal composition of the composite binder was determined through systematic experimentation, yielding a formulation consisting of 80-82% bitumen, 7-11% TPP ash, and 8.5-9.5% ARPR. These proportions were strategically designed to enhance the performance characteristics of the asphalt concrete while promoting environmental sustainability by incorporating industrial waste materials. Physical and mechanical properties of the resulting asphalt concrete were evaluated through assessments of compressive strength, shear stability, water resistance, and durability at various temperatures.

To determine the specific surface area of different types of ash (Sud, cm^2/g), the PSX-12(SP) device was used, which also allows for measuring the average particle size (d, µm). Similar measurements of the specific surface area of ash from the Kyzylorda thermal power plant (Sud, cm^2/g) were carried out using the PSX-12(SP) device, which is also equipped with the ability to determine the average particle size (d, µm). The principle of operation of these devices is based on the dependence of the air permeability of the powder layer on the size of its specific surface, which allows for accurate measurements of material characteristics.

Standard methods established following GOST 30108-94 "Interstate standard: Building materials and products" [15], Sanitary Rules and Regulations SanPiN 2.6.1.2523-09 "Radiation Safety Norms NRB-99/2009" [16] were used to analyse the specific effective activity of natural radionuclides in man-made raw materials. These studies were carried out using the Progress BG gamma-beta spectrometric complex, which includes high-performance components: GEM-40190-C detection system using a high-purity germanium semiconductor; spectrometric amplifier; multi-channel 92X pulse analyser Spectrum Master; and a spectrum imaging and processing system for accurate measurement of radiation parameters of samples.

3. Results

In the world of road construction, the use of fly ash from coal combustion at thermal power plants as a mineral additive in asphalt concrete is becoming increasingly common. This material, which has several unique properties, has a significant impact on the rheological characteristics of asphalt concrete, making it attractive to engineers and builders.

Table 1. Chemical composition of ash

Component name	Ash from Kyzylorda HEC-6	Ash from Almaty HEC-2	Ash from Balkhashskaya HEC	Ash from the Zhezkazgan HEC
Puncture losses	4.95	1.9	4.85	1.9
SiO_2	62.53	60.2	56.2	47.83
$A_{12}O_3$	28.75	30.92	27.7	28.7
CaO	0.612	1.28	1.35	3.36
Fe_2O_3	4D	3.35	6.18	13.16
CO_3	0.209	0.153	0.102	1.42
MgO	1.6	0.577	4.64	1.4
Ha_2O	1.5	0.525	1.16	0.874
K_2O	0.291	0.75	1.18	1.65
TIO_2	0.588	1.17	0.684	1.7
P_2O_5	0.485	0.482	0.358	0.476
RuO_4	0.28	0.219	0.14	-
BaO	-	-	-	-
SrO	0.42	-	-	-
F	-	-	-	-
MnO	0.82	-	0.61	-

Note: HEC – heat and energy central.

3.1. Experimental Design and Testing Methodology

The chemical analysis of man-made aluminosilicate raw materials obtained from the waste of fuel and energy enterprises in the form of fly ash of various compositions was carried out using spectral methods and considering the calcination losses (0.7-4.95%). The data obtained was recalculated by 100%. The analysis results demonstrated (Table 1) that the studied man-made raw materials are characterised by a high content of silicon oxide SiO_2 (30.3-62.53%) and aluminium oxide $A_{l2}O_3$ (8.84-30.92%). The content of calcium oxide, magnesium oxide, sulphur and sulphate compounds (in terms of SO_3), as well as alkaline sodium and potassium oxides (in terms of Na_2O) in the ash component of the ash and slag mixture and the fine-grained mixture of the ash sample, meets the requirements of GOST 25592-91 “Mixtures of ash and slag from thermal power plants for concrete – technical conditions” [17].

Petrographic and microscopic studies revealed that the ash and slag consist of four groups of substances: vitreous, amorphous clay, crystalline and organic (Figure 3). Vitreous substances are formed through the melting of materials at high temperatures. The organic part of the ash consists of coke and semi-coke. The crystalline phase includes grains of quartz, mullite, hematite, kaolinite and feldspar.

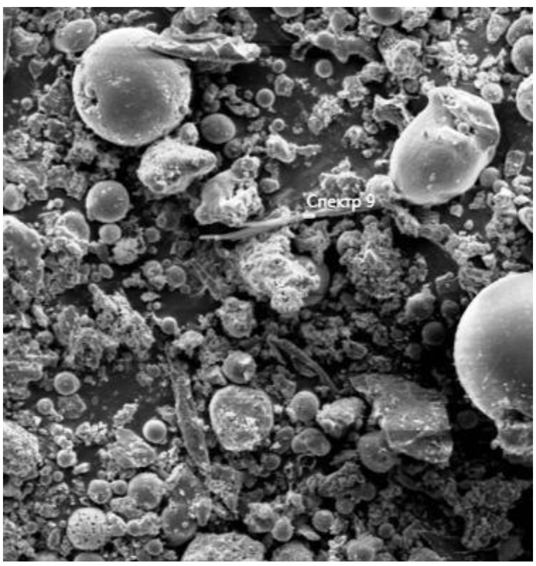

Figure 3. Microstructures of analysed TPP ash

Determination of the true density, average density, porosity level, bitumen absorption capacity and moisture content of ash used as a filler for bitumen [18]. The rheological characteristics of the bitumen were measured using a Rheotest RN4.1 vibrating rotational viscometer and a plate/plate measuring system. A 36 mm diameter plate was used for these measurements, providing a viscosity measurement range of 100 to 10 mPa*s. The physical and mechanical properties of large and small aggregates of the asphalt mixture were analysed using such methods as sieve analysis, specific gravity and absorption tests, Marshall stability and flow test, resilient modulus test, and dynamic modulus test [19]. The methodology for laboratory tests of asphalt concrete included several tests on samples that had been compacted in a moulding machine. The results were then compared with regulatory requirements. The rutting resistance of asphalt concrete was determined using a wheel load meter InfraTest Prutechnik GmbH6 (Germany) following the European standard EN 12697-22. This device simulates the operating conditions of asphalt concrete under the influence of a moving vehicle (wheel load).

As known, the composition of asphalt concrete has a significant impact on its strength characteristics, and to achieve increased strength, this composition needs to be optimised [20]. In this regard, the next step in the research was to develop optimal asphalt concrete compositions, including various combinations of TPP ash, asphalt tar paraffin deposits and bitumen. Therefore, at the initial stage of the study, the impact of the components of the composite binder system “Bitumen – ARPR – ash from thermal power plants” on the final strength of asphalt concrete was analysed. Mathematical planning of experimental work was used to achieve the optimal composition. The results of the analysis of the physical and mechanical characteristics of asphalt concrete depending on the use of ash and bitumen binder are presented in Table 2.

From the data presented, it follows that the compressive strength of asphalt concrete is 2.2-2.5 MPa at 50 ℃, 4.4-5.2 MPa at 20 ℃ and 9.7-9.9 MPa at 0 ℃. The shear stability, assessed by the internal friction coefficient, is 0.85-0.87, and the shear adhesion at 50 ℃ is 0.62-0.86. The water resistance of asphalt concrete is estimated to be in the range of 0.89 to 0.98, and the water saturation is in the range of 1.22-2.2%. Long-term water saturation does not significantly affect the water resistance, which remains in the range of 0.77 to 0.9. Determination of the rheological properties of a composition based on a combination of a rubber-polymer binder, bitumen and ash is aimed at studying the behaviour of bitumen as an elastic material under short-term exposure and as a viscous liquid under long-term loading. Figure 4 shows the resulting asphalt concrete, demonstrating the results of this approach.

Table 2. Physical and mechanical characteristics of asphalt concrete, which vary depending on the use of a particular fly ash binder

Indicators	Requirements: GOST 9128, 2013 for type B, III rating, III DPC	Pure bitumen	Ash from Kyzylorda HEC-6	Ash from Almaty HEC-2	Ash from Balkhashskaya HEC	Ash from the Zhezkazgan HEC
Compression strength, MPa: - at a temperature of 50 ℃ - at a temperature of 20 ℃ - at a temperature of 0 ℃	no less than 0.9 no less than 2 no more than 12	1.6 3.8 10.1	2.2 5.2 9.8	2.3 5.1 9.9	2.3 5.4 9.7	2.5 4.4 9.9
Shear resistance: - coefficient of internal friction - shear adhesion - at a temperature of 50 ℃	no less than 0.80 no less than 0.34	0.84 0.75	0.85 0.72	0.91 0.69	0.87 0.75	0.87 0.69
Crack resistance at tensile strength at 0 ℃, MPa	not less than 2.5 and not more than 7	4.1	4.3	4.4	4.2	4.2
Waterproof	no less than 0.75	0.90	0.94	0.92	0.97	0.98
Water saturation, %	from 1.5 to 4	1.8	2.2	1.39	1.4	1.52
Swelling, %	-	0.2	0.1	0.1	0.1	0.2
Long-term water resistance	no less than 0.65	0.78	0.79	0.77	0.88	0.90

Figure 4. The resulting asphalt concrete

The science known as rheology studies the deformation of viscoelastic materials and the behaviour of liquids as they flow, combining aspects of chemistry, mechanics and physics [21]. In the field of rheology, viscoelastic characteristics are considered, which depend on the structure of the material and can be controlled. In this study, the terms "rheological properties" and "viscoelastic properties" are considered synonymous in the context of asphalt and bitumen. The study of the rheological characteristics of bitumen modelled to simulate the conditions of road pavement operation in summer is carried out by examining its deformation properties at different temperatures and speeds, which was used to assess the resistance of asphalt pavement to puncture and its reaction to additional loads. For the test, samples of ash bitumen binder were prepared, where a certain amount of 60/90 bitumen, up to 0.5 kg, was heated to 160 ℃ and mixed with 0.5, 10 and 15% of each aggregate.

In the fuel and energy sector, all available fillers in the form of thermal power plant ash from solid fuel combustion are mixed for 5 minutes using a low-speed mixer (140±5 rpm) until a homogeneous consistency is obtained [22]. After mixing, bitumen samples with a height of 1.5-2 mm and a diameter of 36 mm, modified with TPP ash, were prepared. The samples were then tested after cooling to room temperature. During the test, the results were obtained and plotted, and the curve was analysed for changes depending on the type and content of ash in the binder and the test temperature (Figure 5). In general, the characteristics of the curves reveal the following feature: the ability of the binder to resist shear stresses decreases with increasing temperature. However, the composition, properties and concentration of the fly ash used as a filler affect the strength parameters of the coating at different temperatures.

When the content of solid fuel combustion waste in the bitumen mixture is increased by 10%, significant changes are observed (Figure 6).

When the ash concentration from the bitumen mass is increased to 15%, the following changes are observed, as shown in Figure 7. When using ash from HEC No. 4 and No. 2, the puncture resistance at temperatures from 46 to 58 ℃ increases by 46 and 29%, respectively, compared to the use of a 10% ash concentration in bitumen. This is an increase of 45 and 41%, respectively, compared to the use of a binder with 15% limestone. At 64 ℃, these materials show a performance improvement of around 55% compared to limestone.

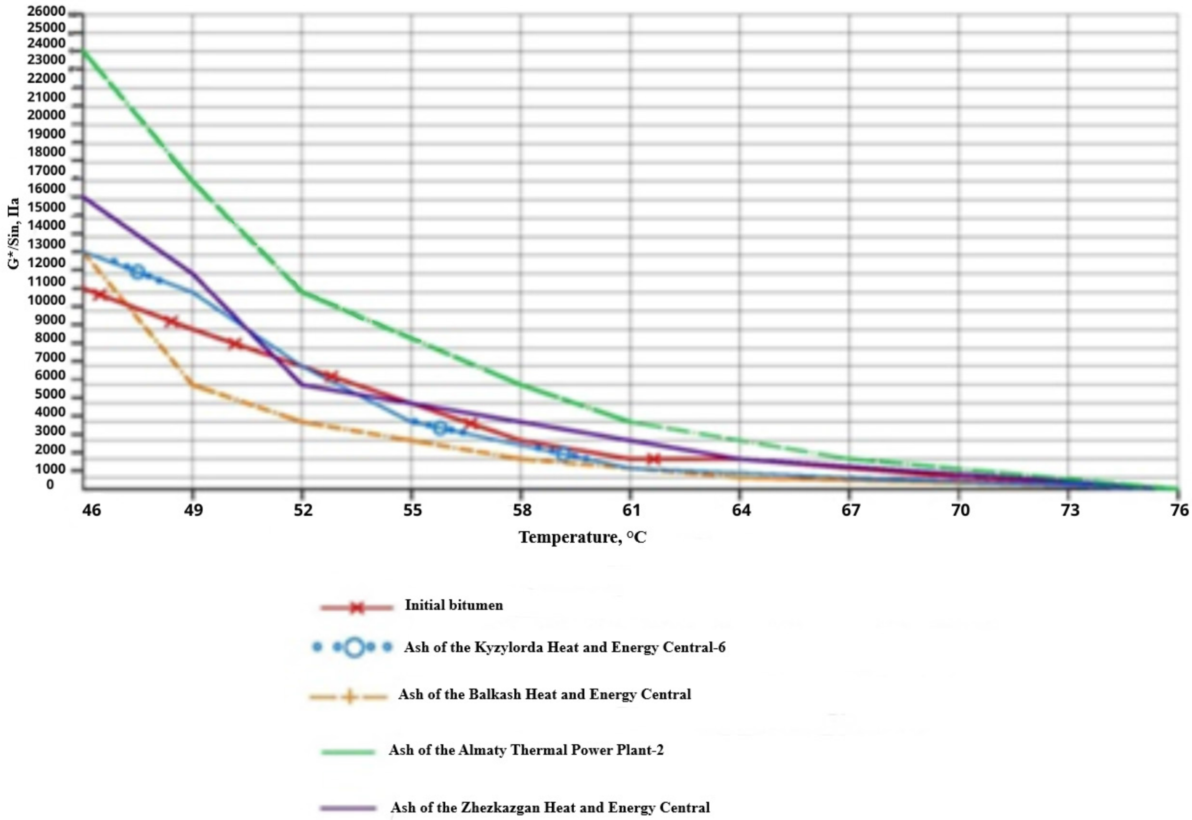

Figure 5. Strength characteristics of asphalt pavement resistant to rutting when using a composition based on HEC ash (5% by weight of bitumen)

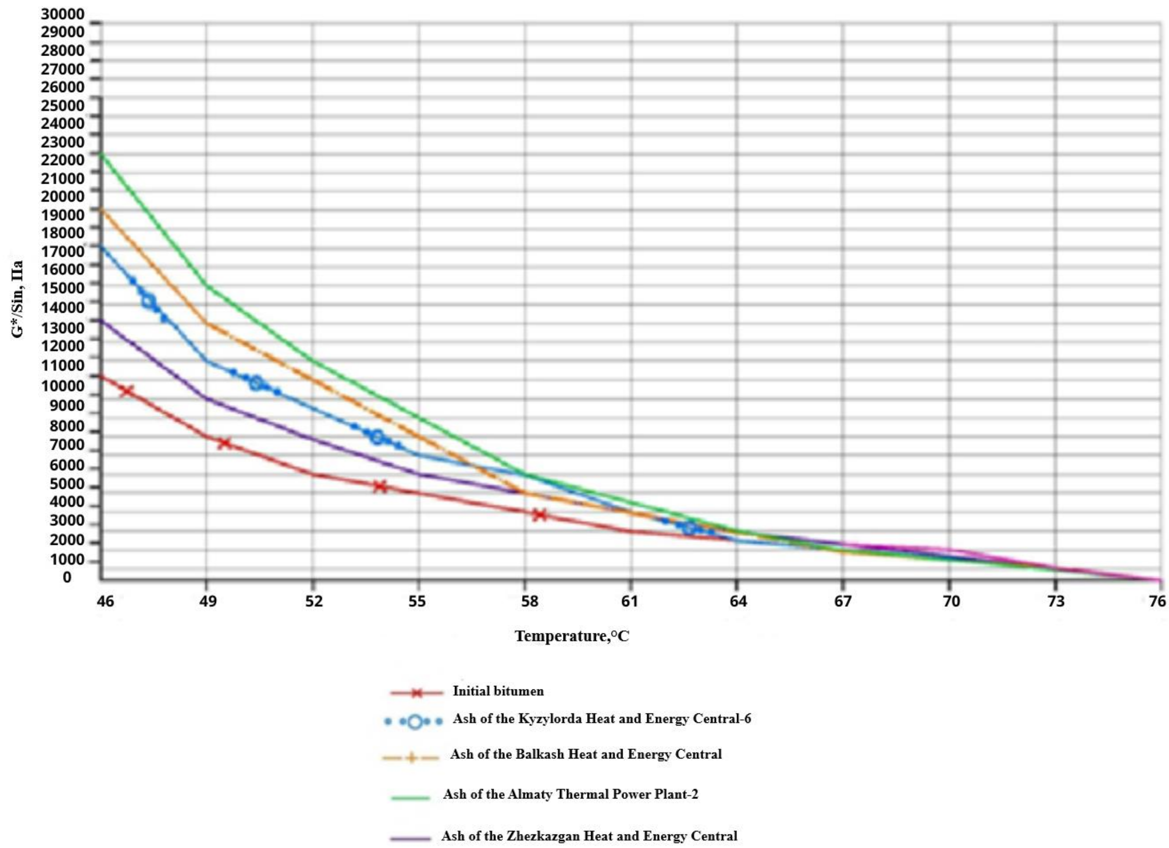

Figure 6. Anti-chipping characteristics of road pavement based on type A asphalt composition obtained from thermal power ash (10% by weight of bitumen)

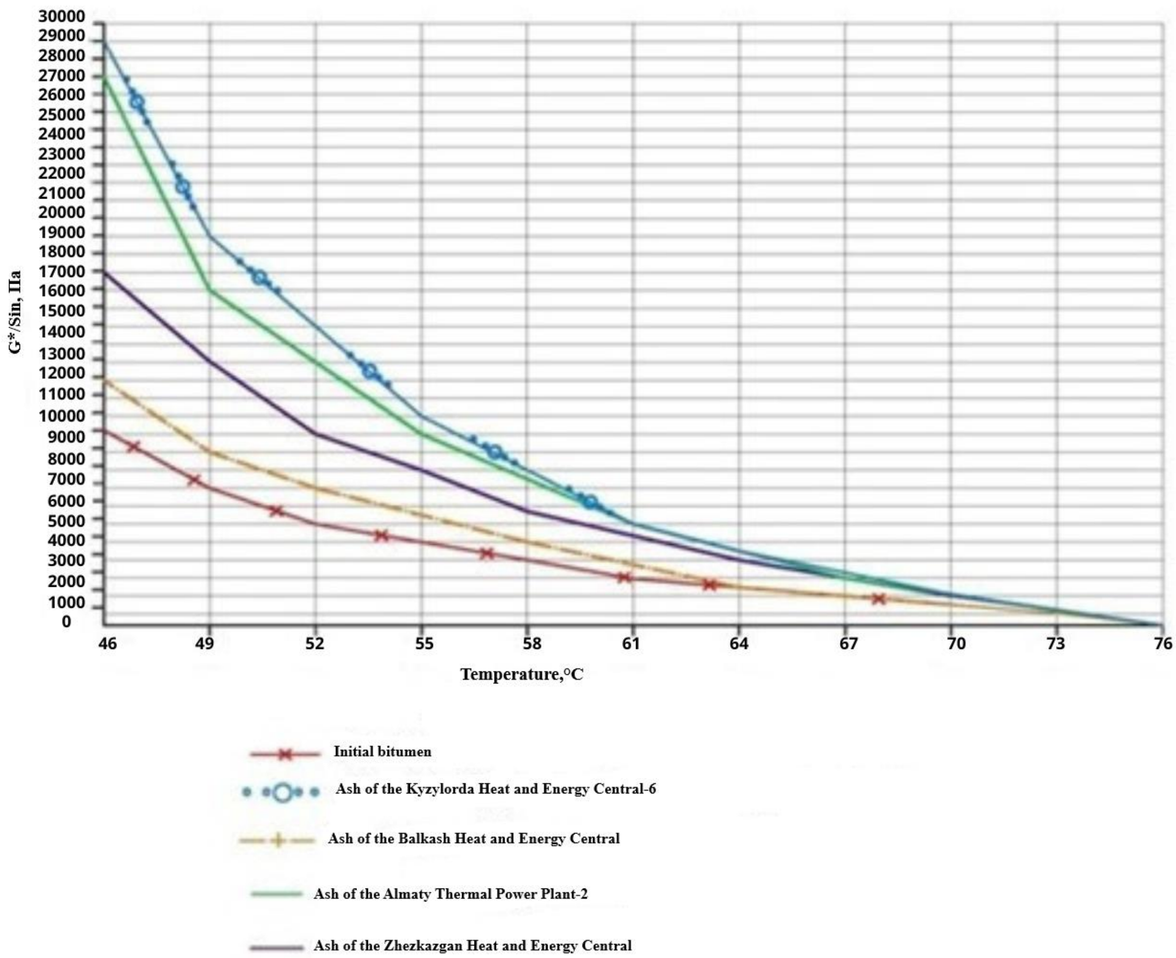

Figure 7. Strength characteristics of a road surface consisting of asphalt-bitumen composition A, including 15% ash by weight of bitumen

The parameter $G*$ /sinδ is primarily associated with the strength characteristics of asphalt binders and mixtures, though it can also relate to anti-chipping characteristics. The complex shear modulus ($G*$) indicates the material's ability to resist deformation under shear loading, with higher values signifying a stiffer binder that is less prone to deformation. The phase angle (δ) reflects the relative contributions of the elastic and viscous responses, where a lower angle suggests a more elastic behaviour. The ratio $G*$ /sinδ provides a measure of binder stiffness under practical loading conditions, which is crucial for evaluating performance. To measure this parameter, asphalt binder samples are prepared and conditioned at specific temperatures, typically between 58℃ and 64℃, before being subjected to testing in a dynamic shear rheometer (DSR). This device applies sinusoidal shear stress to the samples and measures the resulting shear strain across various frequencies, allowing for the calculation of both $G*$ and δ. Although $G*$ /sinδ primarily assesses strength and stiffness, its role in enhancing anti-chipping characteristics is evident, as a stiffer binder is less likely to chip or crack under mechanical stress and environmental factors. Thus, the parameter serves as a key indicator of overall asphalt performance, providing critical insights into material behaviour under operational conditions.

The structuring role of TPP ash is explained by the enhancement of chemisorption through physical adsorption of bitumen and asphalt-paraffin waste due to its specific chemical and mineral composition [23]. This made it possible to improve the mechanical and physical properties of the composite binder based on “bitumen-ash – asphalt resin-paraffin waste” and to increase the performance of the asphalt pavement. The composition of the resulting asphalt concrete is confirmed by a utility model and patents for the invention.

Increasing the concentration of high-calcium man-made raw materials to 10% slightly reduces the viscoelastic properties of ash bitumen binder at 46℃. However, when both ashes are used at 64℃, the stain resistance increases by 15%. The resistance of asphalt concrete based on fly ash bitumen and ARPR binder to denting during operation was also studied. In 2024, the most common road surface defect is potholes [24]. This is due to an increase in the number of vehicles and their carrying capacity, which underlines the need to develop and implement new, high-quality and durable composites for road construction. Particular attention should be paid to the technical and operational characteristics of the materials created. The use of standard methods is mandatory but does not provide a complete assessment of the quality of road construction materials. In this regard, the use of new equipment and modelling techniques is proving to be highly effective, allowing for an accurate assessment of the residual deformation resistance of materials. The test work was carried out as follows:

1. Using an InfraTest Prutechnik GmbH 20-4030 roller (Germany), samples of asphalt slabs measuring 320x260x40 mm were made from dense type B mix.
2. The samples were dried for 12-48 hours in the field at a temperature of 20±2°C.
3. The prepared asphalt concrete samples were placed on the test tables for circular load testing (devices on the left and right, as the tests were carried out on two samples of the same composition), fixed and placed in the chamber of the device until the required test temperature (30-70°C) was reached.
4. The test temperature was selected depending on the bitumen grade: 70°C for asphalt concrete type B and asphalt binders based on bitumen 60/90.
5. After reaching the set temperature, the samples were tested with a circular load of 710 N until the depth of the resulting mark reached the maximum permissible value of 20 mm.

3.2. Test Results and Data Analysis

Figure 8 shows the rutting resistance of asphalt concrete based on the developed asphalt binders.

The data analysis shows that asphalt concrete with raw bitumen without additives reaches a maximum rut depth of 20 mm at 9600-wheel passes. The use of asphalt binders with the addition of asphalt resin-paraffin deposits in asphalt mixtures has improved the resistance to rutting. The use of asphalt concrete made based on ash bitumen with ARPR binder has proven to be effective in increasing their resistance to rutting. This means that such asphalt mixtures are less susceptible to the formation of marks or potholes on the road surface under the influence of traffic. Improving rutting resistance is important for the long-term quality of roads, as it reduces the risk of damage and increases the service life of the pavement.

The study determined that the number of potholes with a depth of 20 mm was 24000, which is 1.5 times higher than the samples made based on pure bitumen without additives. This indicates that asphalt concrete based on TPP ash bitumen with ARPR binder demonstrates higher resistance to mechanical loads and wear compared to traditional asphalt concrete without additives. An increase in the number of potholes indicates a decrease in the strength and wear resistance of the road surface, which determines the importance of employing improved asphalt concrete compositions to ensure the durability and reliability of road surfaces. The effect of ash from thermal power plants can be explained by its ability to serve as a filler that enhances the compactness of asphalt concrete. This binding action has a favourable effect on the properties of both bitumen and asphalt concrete produced with its use. As a result, thermal power plant ash becomes part of the binder composition, which leads to improved binding properties of the material. This, in turn, can lead to an increase in the strength, resistance to mechanical stress and wear resistance of the asphalt pavement. Thus, the use of thermal power plant ash as a binder is a key factor in improving the performance of asphalt mixtures and ensuring a longer service life of road surfaces.

All samples made based on ash from thermal power plants and the agro-industrial complex (AIC) demonstrated resistance that meets the established requirements. For these samples, the number of passes was 15000 and 22500, respectively, which is 1.18 and 1.8 times higher than for the control samples. However, the number of passes for asphalt concrete based on thermal power plant ash and asphalt concrete without additives in Zone 1 was 3000 and 4000 less. Such conclusions obtained with the use of this ash can be explained by the presence and similarity of imperfectly shaped carbon particles, which have a uniform effect on the properties of the binder and asphalt concrete. Thus, the use of thermal power ash in asphalt concrete is not only a technologically efficient solution but also an important step towards the sustainable development of road construction in Central Kazakhstan.

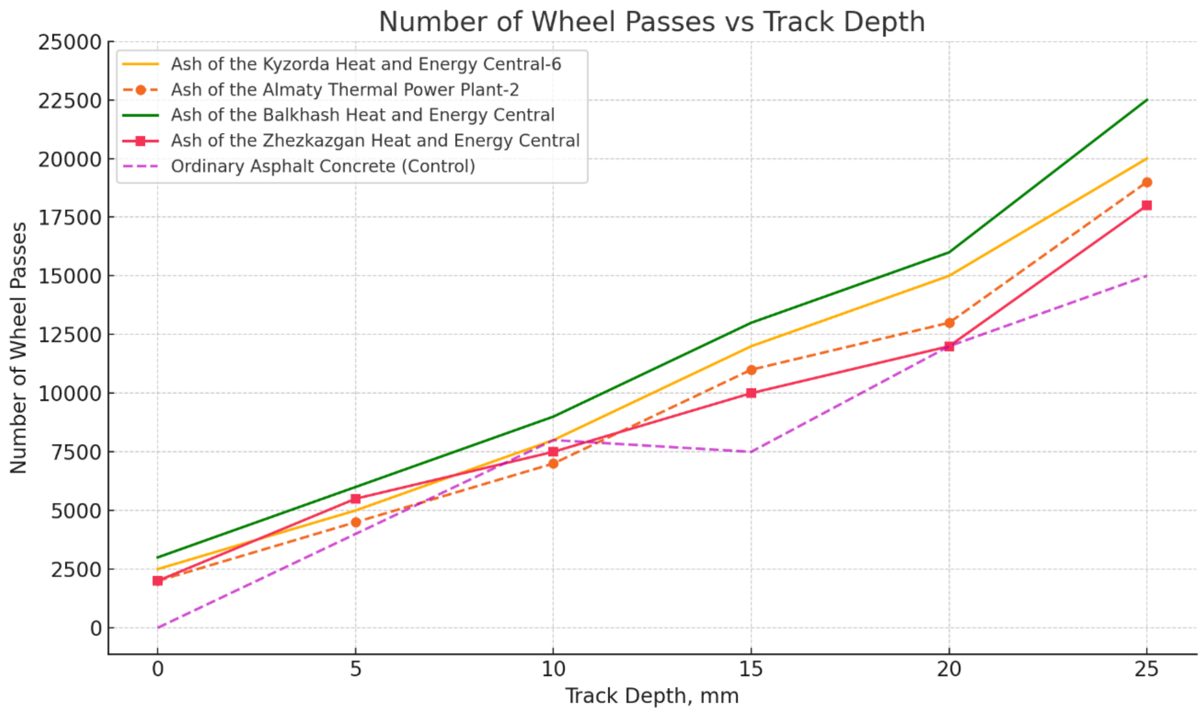

Figure 8. Anti-rutting resistance of asphalt concrete based on fly ash bitumen and ARPR binder

4. Discussion

The study of the rheological properties of asphalt concrete based on asphalt-resin-paraffin deposits from oil and thermal power ash in Central Kazakhstan is an important topic in the context of road construction and infrastructure development in this region. Rheology, as the science of deformation and flow of materials, plays a key role in understanding the behaviour of asphalt mixtures, especially under changing operating conditions and climatic factors. This aspect was also considered in the study by J. Li et al. [25], and they concluded that the consideration of rheological aspects of asphalt concrete based on asphalt tar and paraffin deposits and thermal power ash is an important topic for road construction. This is of interest to researchers because of the potential for creating stronger and more sustainable road surfaces. The findings of the current study echo the conclusions of the researchers, highlighting how the introduction of ARPR and TPP ash significantly alters the rheological properties of the asphalt, leading to improved performance under dynamic loading conditions. However, a more in-depth study of the rheological properties of these materials is required to understand their behaviour under different loading conditions and temperature regimes. Moreover, a study conducted by P.K. Ashish and D. Singh [26] noted that the study of the rheological characteristics of asphalt mixtures using asphalt-resin-paraffin deposits and CHP ash plays a key role in optimising road construction processes. These materials can affect the viscosity, elasticity and deformation resistance of mixtures. These properties can be utilised to create more durable and sustainable pavements. Research determined the optimal proportions of components to achieve the desired asphalt characteristics, including strength and cost-effectiveness, which is consistent with the results of this study.

The main components affecting the rheological properties of asphalt concrete in this case are asphalt-resin-paraffin deposits and thermal power ash. Asphalt tar and paraffin deposits from oil production contain various hydrocarbons that can affect the viscosity and structure of asphalt concrete [27]. Thermal power ash, in turn, has a variety of mineral components that can improve the mechanical properties of asphalt concrete and its resistance to environmental influences [28]. This was also investigated by Y. Wang et al. [29], where the results confirmed that the effect of asphalt resin-paraffin deposits on the rheological properties of asphalt concrete is important to study in the context of road construction. The hydrocarbons in these deposits can change the viscosity of the bitumen, affecting its processing and the strength of the mixture. They also affect the structure of asphalt concrete, which can affect its mechanical properties. The current study supports this notion by showing that both ARPR and TPP ash contribute positively to the chemical composition of asphalt mixtures, leading to notable improvements in mechanical properties and overall performance. S. Dimter et al. [30] also investigated that thermal power ash has an important impact on the mechanical properties of asphalt mixtures. It improves the adhesion between asphalt components such as aggregates and bitumen, which increases the strength and durability of the pavement. In addition, due to its finely dispersed structure, fly ash helps to increase the density of the mixture, which improves its mechanical properties. It is worth noting that thermal power ash also contributes to improving the environmental resistance of asphalt concrete. Due to its chemical nature and mineral composition, fly ash can prevent the destruction of the asphalt pavement structure under the influence of aggressive factors such as moisture, salts and chemical compounds [31]. This effect is especially important in regions with a variable climate and heavy traffic, where asphalt concrete must maintain its qualities for a long time. In this research, it was similarly observed that incorporating TPP ash not only enhanced the mechanical strength of asphalt concrete but also improved its resistance to wear and degradation, indicating that different types of fillers can provide comparable benefits.

One of the main aspects to be considered when considering the rheological properties of asphalt based on these materials is their interaction with bitumen. Bitumen plays the role of a binder in asphalt concrete and determines its rheological characteristics [32]. Therefore, it is important to study how asphalt tar and ash deposits affect the viscosity and elasticity of bitumen, which in turn will affect the rheological properties of the entire asphalt composite. This aspect has attracted the attention of many researchers, including N. Mashaan et al. [33], who emphasise the importance of the influence of asphalt tar and wax deposits and ash on the rheological characteristics of asphalt concrete. Asphalt resin and paraffin emissions from oil production contain a variety of hydrocarbons that can affect the viscosity and structure of asphalt concrete. These components can manifest the physical properties of bitumen, which is the main binder in asphalt concrete, and affect its flowability, elasticity and adhesion. The current study parallels these results, as it was found that the incorporation of ARPR enhances the rheological properties of the asphalt binder, further supporting the idea that waste materials can improve asphalt performance.

R. Penki and S.K. Rout [34] concluded that bitumen plays a key role in the rheological properties of asphalt concrete, especially when exposed to asphalt tar and ash deposits. These components of bitumen can lead to changes in its fluidity, elasticity and adhesion, which directly affects the rheological characteristics of the asphalt composite. Asphalt resin additives containing various hydrocarbons can modify the properties of bitumen, as well as various mineral components that can also affect bitumen. Changes in the properties of bitumen, in turn, will affect its ability to bind aggregates and provide structural strength to asphalt concrete. These results confirm the importance of studying the influence of asphalt tar and ash deposits on the rheological properties of asphalt concrete through their effect on bitumen. Studies show that changes in the rheological properties of bitumen can have a significant impact on the characteristics of the asphalt composite. This opens new perspectives for a deeper understanding of the processes occurring in asphalt mixtures under the influence of these components and for the development of more effective methods for managing their properties. Such research can help optimise road construction processes and create more durable and sustainable road surfaces, which is a key aspect of the region's infrastructure development. Moreover, parameters such as asphalt density and porosity must be addressed, which can also be altered by the introduction of asphalt tar wax deposits and ash. These changes can affect the stability and durability of the road surface, especially in Central Kazakhstan, where climatic conditions can be extreme. Compared to these results, the current study demonstrates that the combination of ARPR and TPP ash can produce a more effective binder system, showcasing how innovative materials can lead to superior road surface performance. T.L.X. Wong et al. [35] addressed this phenomenon and noted that the introduction of asphalt tar and ash deposits into asphalt concrete can affect its luminosity and porosity. Asphalt tar and paraffin deposits resulting from oil production contain various hydrocarbons that can change the composition and compactness of asphalt mixtures. These changes in porosity and density can, in turn, affect its mechanical properties, water permeability and ability to withstand stress. The current research adds to this body of work by specifically demonstrating the effectiveness of TPP ash and ARPR in improving the properties of asphalt mixtures, thus providing a localised context for the benefits of waste recycling in road construction.

J. Hu et al. [36] investigated that the increase in density and decrease in porosity of asphalt concrete usually increase with the increase in its strength and resistance to various types of materials. The more compact design of the material allows it to effectively reduce the load and reduce the likelihood of cracks and deformations [37, 38]. This is especially important in extreme climates where coatings are subject to intense thermal and mechanical stress. These data are consistent with the theses presented in the previous section. The findings of the current research demonstrate that TPP ash serves as an effective filler, enhancing both the mechanical and durability characteristics of the asphalt concrete, which is crucial for the sustainability of road infrastructure. Understanding the influence of density and porosity on pavement stability confirms the importance of researching the rheological properties of asphalt concrete when using asphalt tar paraffin deposits and ash. This allows for optimised road construction and high-quality infrastructure in different climatic conditions. Research in this area optimised the composition of asphalt mixtures and increased their stability and durability. The introduction of asphalt tar and ash deposits into the asphalt concrete composition allows for its rheological properties, including adhesion, frost resistance and deformation resistance. Z.A. Jattak et al. [39] determined that optimisation of asphalt mixtures with asphalt tar and wax deposits and ash is an important area in road construction. The introduction of these components improves the mechanical properties of asphalt concrete, such as strength and wear resistance. Asphalt tar and paraffin deposits from oil production affect the viscosity of bitumen, which improves its adhesion [40].

Ash from thermal power plants contains mineral components that improve the structure of the mixture [41, 42]. These changes help to improve the quality and durability of road surfaces. This study complements these findings, as it was found that incorporating TPP ash not only increased strength and stability but also contributed to environmental sustainability, emphasising the benefits of using industrial by-products in asphalt concrete.

In conclusion, the study of the rheological properties of asphalt concrete based on asphalt-resin-paraffin deposits from oil fields and thermal power ash in Central Kazakhstan is of great importance for the development of infrastructure and road safety in this region. Such research will help optimise the composition of asphalt mixtures, increase their stability and durability, and reduce road construction costs by using local resources and recycling industrial waste.

5. Conclusions

Spectral methods were used to perform chemical analysis of anthropogenic aluminosilicate raw materials obtained from waste from fuel and energy enterprises in the form of fly ash. The analysis addressed the calcination losses, which ranged from 0.7% to 4.95%, and the data were recalculated to 100%. The analysis showed that the studied man-made raw materials are characterised by a high content of silicon oxide (SiO_2) ranging from 30.3% to 62.53% and aluminium oxide (Al_2O_3) from 8.84% to 30.92%. Microscopic analysis and petrographic studies have shown that the composition of ash and slag contains four main categories of substances: vitreous, amorphous clay, crystalline and organic. The vitreous components are in the form of spherical formations that have undergone melting at high temperatures.

A study of the rheological properties of bitumen using man-made material derived from fuel and energy industry waste at concentrations of 5, 10 and 15% by weight of bitumen determined that fly ash acts as an effective additive. It increases the viscosity at temperatures similar to those of summer pavements and helps to improve the deformation resistance of the binder. This conclusion is confirmed by the composition of the resulting asphalt concrete, which has been protected by utility models and invention patents.

The study highlights the significant improvements achieved in the mechanical properties of asphalt concrete through the incorporation of thermal power plant ash and asphalt-resin-paraffin deposits. The findings indicate that the modified asphalt mixtures exhibited enhanced compressive strength, demonstrating a greater ability to withstand loads compared to conventional formulations. Additionally, the shear stability and shear adhesion properties were markedly improved, indicating a stronger bond within the mixture and enhanced resistance to deformation under stress. Furthermore, the modified mixtures showed superior water resistance and reduced water saturation levels, suggesting that the incorporation of these materials not only optimises performance in terms of durability but also contributes to a more resilient asphalt concrete that can better withstand environmental challenges. These results underscore the potential of utilising industrial by-products to enhance asphalt performance while promoting sustainable practices in road construction.

The efficiency of using man-made waste can vary depending on its composition or structural features. This was demonstrated in the case of asphalt concrete samples produced with the use of HEC ash of various compositions, which in all cases showed increased resistance to denting. Additionally, the positive results of using different types of ash can be determined by the structure and dispersion of their surface. These factors contribute to the formation of a dense asphalt structure, which makes it more resistant to external influences compared to the material without additives. One of the limitations of the study is the limited amount of data on the reaction of asphalt concrete to different concentrations of asphalt tar and ash deposits, which requires further research to obtain more comprehensive results.

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