Строительные материалы и изделия
Construction Materials and Products

journal homepage: https://bstu-journals.ru

ISSN 2618-7183

DOI: 10.58224/2618-7183-2025-8-3-1

Development of a modified bitumen emulsion to enhance the operational properties of asphalt concrete

Syrmanova K.K. *[1], **Tuleuov R.M.** [1], **Kaldybekova Zh.B.** [1], **Baizhanova Sh.B.** [1], **Kolesnikova O.G.** [1], **Zhumayev Zh.Zh.** [2], **Nigmetov M.Zh.** [2], **Yesbolay G.I.** [2]

[1] M. Auezov South Kazakhstan University, Kazakhstan,
[2] M.Sh. Yesenov Caspian University of Technology and Engineering, Kazakhstan

Abstract. At present, the primary objective of the road construction industry is to increase the service life of road pavements by implementing innovative technologies that meet modern standards of operational reliability. The key advantages of bitumen emulsions were analyzed, including improved adhesion and cohesion, environmental safety, resistance to water exposure, rapid curing and opening to traffic, applicability under cold conditions, as well as enhanced stability and durability. The research findings confirm the benefits of using bitumen emulsions in road construction, contributing to high-quality and long-lasting pavement performance. Studies were conducted on the modification of petroleum bitumen. The additional incorporation of Kulantau vermiculite into the composition enhances and stabilizes adhesion across a wide range of ambient humidity and temperature conditions. The adhesion process can be regarded as the adsorption of bitumen emulsion on the surface of mineral aggregates. Adsorption occurs through intermolecular interactions, and adhesion is improved by strengthening these interactions, which is achieved by increasing the activity of the bitumen emulsion through the introduction of additives with active functional groups. It was found that incorporating secondary polyethylene and Kulantau vermiculite into asphalt concrete leads to a noticeable decrease in the air void content. This reduction enhances the material's resistance to moisture and freeze-thaw cycles.
Keywords: bituminous binder derived from petroleum, bitumen-based pavement material, secondary polyethylene, Kulantau vermiculite, polymer-bitumen emulsion, water resistance, frost resistance,, adhesion

Please cite this article as: Syrmanova K.K., Tuleuov R.M., Kaldybekova Zh.B., Baizhanova Sh.B., Kolesnikova O.G., Zhumayev Zh.Zh., Nigmetov M.Zh., Yesbolay G.I. Development of a modified bitumen emulsion to enhance the operational properties of asphalt concrete. Construction Materials and Products. 2025. 8 (3). 1. DOI: 10.58224/2618-7183-2025-8-3-1

*Corresponding author E-mail: syrmanova.kulash@mail.ru

Received January 10, 2025; Received in revised form March 14, 2025; Accepted June 19, 2025

1. INTRODUCTION

The modern development of automobile transport is characterized by high traffic intensity of freight vehicles and an increase in dynamic loads on road pavements.

The principal structuring component of asphalt concrete is petroleum road bitumen. The performance of asphalt pavements is heavily influenced by the quality of the bituminous binder, since the thermoplastic behavior of asphalt mixtures largely depends on the characteristics of the bitumen applied. Practice shows that bitumen produced by oil refineries often fails to meet the requirements of national standards, particularly in terms of adhesion, heat resistance, brittleness temperature, and ductility.

Currently, the main objective of the road construction industry is to extend the service life of pavements through the implementation of innovative developments that meet modern performance reliability standards. A promising approach to enhancing the performance and longevity of asphalt concrete surface layers involves the incorporation of bituminous binders modified with special additives, polymers, and surfactants, which enhance their physical and mechanical properties. Asphalt pavements based on such modified binders provide the necessary thermal crack resistance, high adhesion durability, heat resistance, shear stability, and long-term mechanical strength during operation, thereby offering greater reliability and safety for vehicular traffic. Thus, the use of polymer additives in road construction reduces the costs associated with the maintenance and repair of roadways.

Operational experience indicates that traditional road construction materials used in pavement layers do not fully ensure long-term performance under complex geocryological conditions, as evidenced by the premature (relative to design life) deterioration of asphalt concrete surfaces.

It is evident that the strength and durability of asphalt concrete under such conditions depend on the preservation of adequate shear resistance and the required crack resistance. These performance characteristics are governed by the bitumen’s viscosity, which must be sufficient to withstand the prevailing shear and tensile stresses over time under variable temperature conditions.

Numerous studies conducted to establish quantitative criteria for assessing the crack resistance and shear stability of asphalt concrete did not lead to definitive conclusions. This is largely due to the complex composition and structure of asphalt concrete, as well as the time-dependent variability of its rheological properties with temperature changes. One effective approach to improving asphalt concrete performance is the use of various functional additives. Thus, the development of new asphalt concrete formulations incorporating such additives remains a highly relevant research direction.

The prolonged exposure of asphalt concrete pavements to moisture weakens structural bonds, leading to the disintegration of mineral aggregates. This process accelerates pavement wear and reduces the service life of the material.

The strength and water resistance of asphalt concrete largely depend on the properties of the binders and mineral materials used [1].

An urgent task remains the improvement of road bitumen quality through the development of new technical and technological solutions to achieve high physical and mechanical properties.

This study aimed to examine how polyethylene and Kulantau vermiculite influence the moisture and freeze-thaw resistance of asphalt concrete, as well as to develop and implement new compositions of modified polymer-bitumen emulsions and examine the structural stability of asphalt concrete pavements under various weather and climatic conditions.

2. METHODS AND MATERIALS

In many regions of the republic, frequent fluctuations between positive and negative temperatures are observed during the autumn-winter and spring periods. The primary cause of asphalt pavement deterioration associated with poor water resistance is the weak bonding between the bituminous binder and the mineral aggregate surface, particularly when fillers derived from acidic rocks are employed.

Enhancing the quality of bitumen and asphalt mixtures remains a key priority in the road construction sector worldwide [1-2], as the bitumen currently used in road construction fails to meet modern requirements for the following reasons: firstly, it lacks crack resistance, especially in winter;

secondly, it has an insufficient temperature range for effective performance; and thirdly, it is non-elastic under the conditions of modern intensive vehicular traffic, which induces repeated dynamic impacts on the road surface.

Organic binders should be elastomers and characterized by high elasticity to large reversible deformations throughout the entire range of operational temperatures.

In contrast to traditional road bitumen, bituminous emulsions provide strong adhesion to the substrate, which is facilitated by the electrostatic attraction between the positively charged cationic emulsion and the negatively charged surface of the pavement. Owing to its water-like viscosity, the emulsion distributes evenly, penetrating surface pores and irregularities with ease. Additionally, the application of bituminous emulsions at temperatures ranging from 30°C to 70°C makes their use safer. The advantages of bitumen emulsions include: a 20-40% reduction in binder consumption, extension of the road construction season, reduced energy consumption, and a decrease in harmful emissions into the atmosphere.

The active production and utilization of emulsions began in the 1990s. The global production of road bitumen emulsions exceeds 7 million tons annually [3]. The consumption share of bitumen emulsions by country is shown in Fig. 1.

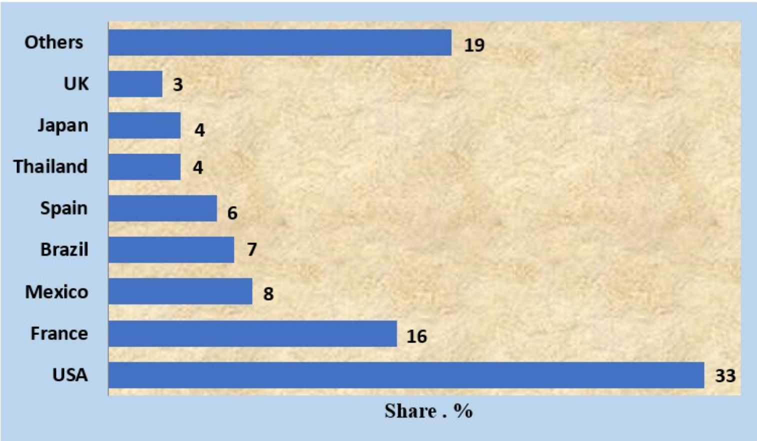


Fig. 1. Share of bitumen emulsion consumption by country.

An effective way to improve the quality of road bitumen is to regulate its properties through the use of various modifying additives based on polymer waste. The introduction of modifiers improves the key properties of polymer-bitumen binders (PBB), increasing the softening point, lowering the brittle fracture temperature, and enhancing adhesion. Polymer modification of bitumen is among the most widely adopted techniques in road construction and pavement maintenance. Meanwhile, the volume of industrial and consumer polyethylene waste is increasing year by year, with disposal methods remaining inconsistent and inadequate.

Research from multiple countries shows that the compatibility between polymers and bitumen depends largely on the chemical composition of the bitumen and the characteristics of the polymer. A polymer is deemed compatible if its blend with bitumen remains stable over time, maintaining colloidal equilibrium without phase separation. Based on extensive studies by various authors [4-5], several conclusions were drawn: - Linear polymers exhibit better miscibility with bitumen compared to polymers with complex branched structures; - The proportion of aromatic and paraffin-naphthenic hydrocarbons in bitumen strongly affects the mixing process; - High asphaltene content in bitumen complicates the production of modified bitumen; - The method of mixing and the degree of polymer dispersion within the binder are critical factors. When polymer microparticles are introduced into bitumen, the viscosity of the mixture increases if the polymer partially melts or interacts with the lighter fractions of bitumen. Swelling of the polymer in bitumen causes the light oil fractions to bind with the polymer, enriching the remaining bitumen with heavier components such as asphaltenes and resins. This process leads to increased viscosity and elasticity of the modified binder. Currently, polymer waste is widely utilized to improve binder quality and the durability of asphalt concrete pavements. According to A. Onishchenko et al. [6], incorporating secondary polyethylene – including low-density polyethylene (LDPE) derived from agricultural films used for 6-8 months and high-density polyethylene (HDPE) sourced from packaging and containers – into asphalt mixtures maintains high mechanical strength and deformation resistance. The findings presented in Table 1 confirm that secondary polyethylene possesses sufficient mechanical and structural properties to serve effectively as a bitumen modifier.

Table 1. Physico-mechanical properties of primary and secondary polyethylene.

Indicator	Primary polyethylene		Secondary polyethylene	
	low-density	high-density	low-density	high-density
Tensilestrength. MPa	16	22-45	8.8-10	14-29
Elongation at break. %	600-800	300-500	170-220	100-250
Frost resistance. ºC	-70 and below		-40…-50	-30…-40

Thermoplastics modify bitumen by creating a rigid spatial network that resists deformation. A continuous spatial network of thermoplastic forms when its content in the binder reaches approximately 6%. Thermoplastics enhance cohesion, heat resistance, elasticity, and adhesion properties while reducing the brittleness of the binder at subzero temperatures. Most thermoplastics dissolve well in bitumen at temperatures of 150-170°C. Although these polymers exhibit high strength, they are not sufficiently crack-resistant at extremely low temperatures. Homogenization is characterized by the partial breakdown of polyethylene and bitumen macromolecules, leading to the formation of free radical valencies. As a result, polyethylene and bitumen molecular fragments react with each other, enabling chemical interaction between the naphthenic components of bitumen and the polymer matrix. This process creates a new structure in which the polar and amorphous bitumen components bond with the nonpolar, structurally viscous polyethylene.

Water exerts a notably damaging influence on asphalt concrete during cycles of freezing and thawing. When moisture enters the pores of the material, it causes the bitumen coatings to separate, weakening the internal bonds of the asphalt concrete. This deterioration is exacerbated by the expansion of water as it freezes. At low temperatures, the bitumen films become brittle, while the freezing water increases in volume, creating significant stress on the pore walls. These stresses can induce microcracks, which fill with water upon thawing and continue to propagate as more water penetrates. Thus, the combined effects of moisture and freezing temperatures severely impair the integrity of asphalt concrete [2].

Simultaneously, water resistance, governed by the strength of the adhesion between the binder and the mineral aggregate surface, remains a critical factor affecting the longevity of pavement structures [5-7]. The literature contains limited data on the durability of asphalt concrete produced with polymer-modified bitumen.

In this context, incorporating secondary polyethylene emerges as a promising strategy. This material contains functional groups that can improve bonding with mineral aggregates, even those composed of acidic rocks, which in turn enhances the water resistance of the asphalt mixture. Additionally, Kulantau vermiculite was used in this study to produce bitumen emulsions. The material increases the specific surface area, which gains additional energy capacity, ultimately leading to improved bonding with bitumen.

The study was carried out using standard methodologies and equipment. To evaluate the effect of polymer waste on asphalt concrete properties, polymer-bitumen blends were produced using bitumen modified with secondary polyethylene.

BND 70/100 bitumen served as the base binder for preparing the modified mixtures. In the modified bitumen emulsion based on petroleum bitumen, petroleum bitumen, an emulsifier, secondary polyethylene, Kulantau vermiculite of domestic production, and other components were used.

Petroleum bitumen BND 70/100, manufactured by Kazakhoil JSC, is a widely produced petroleum refining product. It exhibits a range of important technical characteristics: ductility at 25°C – 115 cm, softening point – 48°C, brittleness temperature – 20°C, and flash point – 240°C [8].

The modified bitumen emulsion based on petroleum bitumen incorporates Kulantau vermiculite – a mica-like magnesium-iron aluminosilicate with a variable chemical composition and an expandable crystal structure, classified within the trioctahedral hydromicas [9-10]. Vermiculite is a unique natural mineral with exceptionally high innovative potential.

The chemical formula of vermiculite is (Mg, Fe^{2+}, Fe^{3+}) $[(SiA1)_4, O_{10}]$ $[OH]_2{\cdot}4H_2O$. It is found in golden-yellow and brown hues. In industry, thermally treated vermiculite, calcined at 1000-1300 °C, known as expanded vermiculite, is used.

Vermiculite, being an environmentally friendly and practically inert material, attracts diverse interest. Its main and practically most valuable property is its ability to expand when heated, transforming into a lightweight, porous, granular material with high thermal and sound insulation properties. The calcined vermiculite masses are also characterized by increased chemical and fire resistance, high covering capacity, good resistance to weathering, non-condensation of moisture, and a low coefficient of thermal expansion. The quality of expanded Kulantau vermiculite (EKV) depends on the optimization of the thermal process, and the method of extraction and development expands its application prospects, reduces production costs, and lowers the cost of products, provided that the raw material is local.

The properties of vermiculite are as follows:

Bulk density: 70-180 kg/m^3 (depending on particle size)

Water absorption capacity: 400-530%

pH: 6.8-7.0 (neutral to weakly alkaline)

Structurally, expanded Kulantau vermiculite (hereafter EKV) is an anisotropic, layered material containing air trapped within its pores. Physical and chemical characterization of EKV through techniques such as X-ray analysis, spectroscopy, and thermogravimetric methods reveals that its particles are composed of thin plates separated by air layers. Upon heating to temperatures up to 1000°C, the volume of EKV expands by more than 25 times.

The technical benefits of EKV include chemical inertness, low density (ranging from 80 to 200 kg/m³), thermal stability, and low thermal conductivity (λ = 0.48-0.06 W/m·°C). Additionally, it exhibits excellent sound absorption, low moisture absorption, notable adsorptive properties, and resistance to biological degradation. Being environmentally safe and non-toxic to humans, EKV has found widespread application in both industrial and residential construction. It is also commonly used as a cost-effective and functional filler in the manufacture of fire-resistant and thermal insulation materials [2-4].

EKV demonstrates elastic behavior, as evidenced by the partial recovery of its height after the removal of a compressive load [2, 5]. The overall deformation under axial compression is a combination of elastic and permanent (residual) deformation, largely due to the air trapped between the layered plates. Additionally, EKV shows anisotropic physical and mechanical properties: its strength perpendicular to the cleavage plane is lower than that parallel to it. The former strength characteristic governs the material's deformability, while the latter reflects the brittleness of expanded vermiculite.

To reduce energy (by 25-40%) and labor costs for roadwork, the EMBIT emulsifier was used. This emulsifier allows saving 10-30% of bitumen by improving the coating of mineral material with the emulsion and enables patching and laying work under adverse weather conditions. The technical characteristics of the EMBIT emulsifier are as follows: appearance at 25°C – a mobile liquid ranging from yellow to dark brown; density at 20°C – not less than 0.92 kg/m^3; dynamic viscosity at 25°C – not more than 300 mPa·s [11].

Experimental batches of modified bitumen emulsion were obtained on an experimental installation using petroleum bitumen, and the physicochemical properties of the developed bitumen emulsion were determined in a mobile laboratory. The bitumen composition was prepared by introducing expanded Kulantau vermiculite (fraction 0.1-1 mm) into bitumen heated to 75-80°C while mixing. For the resulting composition, conditional viscosity, softening point, and ductility at 25°C were determined.

When determining the conditional viscosity of the bitumen emulsion, the content of bitumen in the emulsion has the greatest influence on the viscosity value. The viscosity of the bitumen emulsion is characterized by a relative value, which is determined using special viscometers in accordance with GOST R 58952.1National Standard. Public Roads – Bitumen Road Emulsions – Technical

Requirements, Standartinform, 2020.According to this method, viscosity is characterized by the time required for 50 ml of bitumen emulsion to flow through a calibrated orifice of the viscometer at a specified temperature [12].

The stability of the prepared bitumen emulsion (BE) samples was assessed by measuring the duration – expressed in days – during which the emulsion maintained, to some degree, its original characteristics. Using this approach, the primary outcome of the emulsion testing was quantified as the destruction time [12].

The method for determining the breakdown index is based on the interaction of bitumen with mineral material. A certain amount of bitumen emulsion is mixed at a constant speed, and filler is added. After complete breakdown of the emulsion, the mass of quartz sand required for the breakdown of 100 g of emulsion is determined.

For assessing adhesion, both visual inspection and quantitative measurements were employed. The evaluation focused on the condition and amount of binder film remaining on the surface of mineral samples coated with bitumen and disrupted emulsion after boiling.

Porosity tests of the polymer-bitumen emulsion (PBE) were performed in accordance with GOST R 58401.8-2019. The fundamental aspect of the method includes measuring the bulk density of the asphalt concrete and the volume of the compacted sample, determined by hydrostatic weighing, E (cm^3) for each sample.

The volume of air voids in asphalt concrete, P_a (%), was determined using the formula:

$$P_a=(G_{mm} - G_{mb})/ G_{mm}) 100,$$

where: Gmb – the bulk density of compacted asphalt concrete (g/cm^3),

Gmm – the maximum density of asphalt concrete (g/cm^3).

Next, the volume of air voids, V_a (cm^3), in the compacted sample is calculated using the formula:

$$V_a = P_a E/100.$$

The water resistance coefficient was measured following GOST 58401.18-2019, while the frost resistance of bitumen emulsions was assessed according to GOST 12801-98. The frost resistance was evaluated by analyzing changes in the physicochemical properties of the samples after undergoing 5 to 50 freeze-thaw cycles [3].

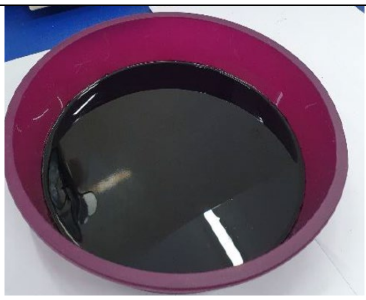
The penetration depth, softening point, and ductility of the bitumen extracted from the emulsion were determined according to [12].

Before testing, the emulsion is poured into a vessel with a volume of at least 500 ml, placed on an electric stove, and the water is evaporated, avoiding intense boiling, while stirring periodically. Evaporation is complete when the release of steam bubbles stops, and the surface of the bitumen becomes mirror-like. For the bitumen extracted from the emulsion, the penetration depth, ductility, and softening point are determined.

The reliability of the research results was ensured through the use of state standards, regulatory documents, a wide range of research methods with certified and calibrated high-tech equipment, the application of modern research techniques, the convergence of theoretical and experimental studies, and reproducibility of results from a large number of experiments.

3. RESULTS AND DISCUSSION

Conducting research and obtaining data on the effectiveness of modifying additives for regulating the performance characteristics of polymer-bitumen materials allowed the production of laboratory samples (Fig. 2A) and experimental batches of polymer-bitumen materials (Fig. 2B). A photograph of the equipment used for producing bitumen emulsion is shown in Fig. 3.



A)

B)

Fig. 2. Polymer-bitumen emulsion obtained in the laboratory (A) and at the experimental site (B).

Fig. 3. Non-standard equipment for producing bitumen emulsion.

It is known [4-6] that polymers have a positive effect on the characteristics of bitumen and asphalt concrete. To investigate the application of secondary polyethylene in asphalt concrete mixtures, experimental research was carried out on the physical and mechanical properties of low-density polyethylene derived from agricultural film used for 6-8 months. Distributing within the binder structure, the polymer components of the modifier alter its properties, contributing to increased material resistance to traffic and climatic impacts. The effect of the additive on the properties of asphalt binder and asphalt concrete largely depends on the quality of its distribution within the mixture during preparation.

The findings of the study are summarized in Table 2, which demonstrates that secondary polyethylene maintains adequate strength and deformation properties, making it suitable for use as a modifying additive in bitumen.

Table 2. Main characteristics of polymer-bitumen emulsions.

№	Indicators	Emulsions		
		BE*	BE+PE**	BE+PE+KV***
1	Conditional viscosity, not more than	166	158	145
2	Stability against breakdown during 7-day storage, not more than	5.8	5.6	5.0
3	Breakdownindex	154	182	225
4	Adhesion to mineral material, %, not less than	55	82	94

* Bitumenemulsion.
** Polymer-bitumenemulsion.
*** Polymer-bitumen emulsion modified with Kulantau vermiculite.

The interaction between bitumen and a material characterized by a high specific surface area and fine porous structure causes changes in the bitumen's group composition due to the selective diffusion of oils and resins into the material. This phenomenon results in the modification of the properties of bituminous layers on the surfaces of particles and the formation of durable bitumen films on the surface of the grains. In this study, expanded vermiculite was used for this purpose, as it demonstrates high efficiency during the activation phase [9] (Fig. 4).

A) 4-7 mm B) 0.1-1 mm

Fig. 4. Kulantau vermiculite.

The impact of expanded Kulantau vermiculite on the quality characteristics of bitumen-vermiculite mixtures designed for highway construction and repair under diverse natural and climatic conditions was examined.

To validate the theoretical findings [13-14] that adding expanded vermiculite enhances the thermal and structural-mechanical properties of bitumen-vermiculite mixtures used in the construction and repair of asphalt concrete pavements – primarily through reduced thermal conductivity and improved structuring of the bitumen binder – polymer-bitumen-vermiculite compositions were prepared. This was achieved by incorporating EKV (fraction 0.1-1 mm) into the base bitumen heated to 80°C during mixing. Viscosity and plasticity characteristics were measured, including the softening point determined by the "Ring and Ball" method, ductility, and penetration of the resulting polymer-bitumen-vermiculite emulsion samples. Crack resistance was assessed based on the degree of degradation of the bitumen-vermiculite mixture (BVM), characterized by the ratio of the compressive strength limit ($R_{compr.}$) to the bending strength limit ($R_{bend.}$). The lower the degree of destruction, the higher the crack resistance of the material.

Fig. 5 presents the graphs illustrating the changes in the properties of the modified bitumen emulsion depending on the content of expanded vermiculite.

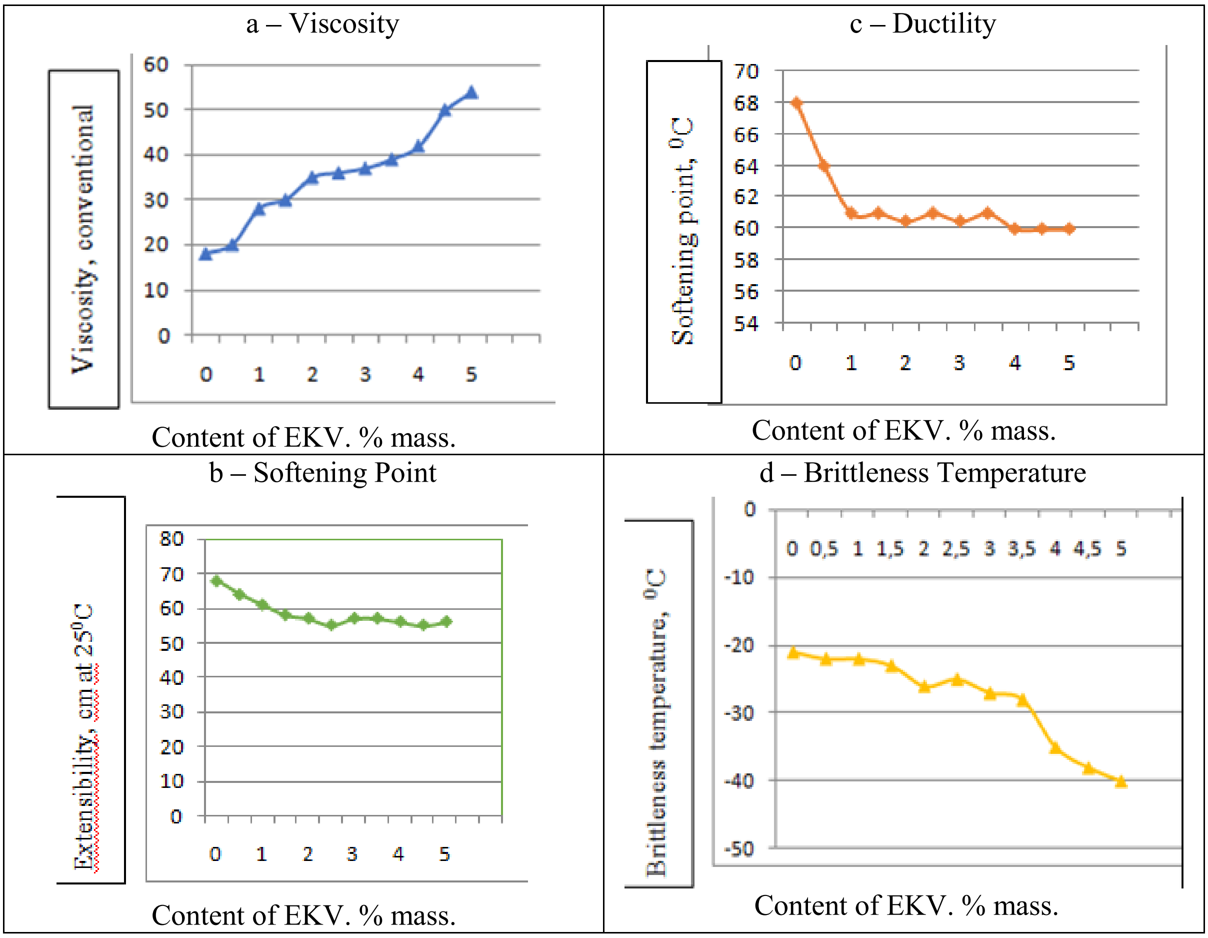


Fig. 5. Changes in the properties of modified bitumenemulsion based on petroleum bitumen depending on the content of expanded vermiculite.

The data indicate that increasing the proportion of expanded Kulantau vermiculite (EKV) in the bitumen binder leads to a rise in the softening point of the composition, while both penetration and ductility values decline at standard temperature conditions (25°C). Predictably, the extent of material degradation also diminishes, which suggests enhanced resistance to cracking.

Based on the analyzed performance characteristics of the bitumen – vermiculite mixtures, the most effective proportions of EKV in petroleum bitumen were determined.

The bitumen-vermiculite mixture containing 4 ± 0.5% by weight of expanded vermiculite demonstrates enhanced thermal stability, as evidenced by an 18-26% increase in the softening point, and improved frost resistance, reflected in a 33-38% reduction in brittleness temperature. The observed decrease in ductility during tensile testing, compared to a uniform bitumen binder, is likely due to the presence of relatively coarse mineral particles introduced into the formulation.

The role of modifying additives in regulating the operational indicators of polymer-bitumen emulsion.

The use of Kulantau vermiculite as a mineral filler increases the softening point by 60-70% and lowers the brittleness temperature to -(38-40)°C. This also improves the adhesion of the polymer-bitumen emulsion, which enhances the strength and water resistance of the road surface.

Additionally, the technological process is simplified as mixing is performed using a paddle-type stirrer with a rotation speed not exceeding 60 rpm, ensuring the necessary homogeneity of the composition. Vermiculite possesses a notable ability to adsorb and efficiently captures substances generated during the oxidation of hydrocarbons, including resins, oxygenated compounds, and various heteroorganic by-products [10]. The choice of expanded Kulantau vermiculite is also determined by its availability and relative affordability.

The next stage in studying the performance properties of the modified bitumen emulsion involved the investigation of the air void content in specimens based on the modified binder, which revealed a consistent trend (Fig. 6). As expected, the air void content in the samples with the modified binder decreases with an increase in the concentration of recycled polyethylene. This indicates that the composition contains a large number of closed pores, which will subsequently contribute to enhanced frost resistance of the pavement.

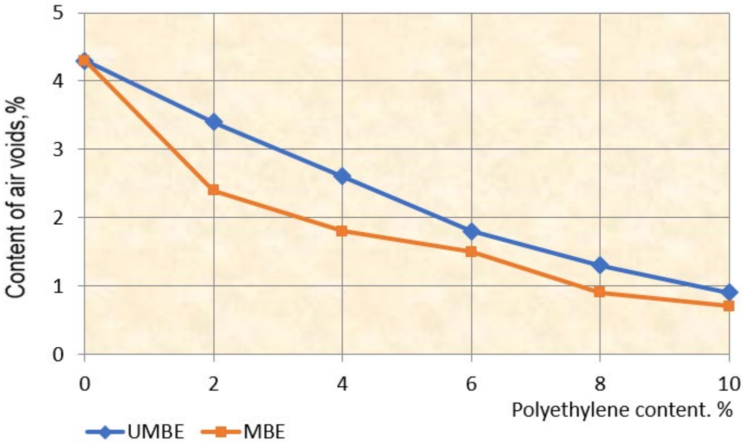


Fig. 6. Effect of air void content in unmodified bitumen emulsion (UMBE) and modified bitumen emulsion (MBE) depending on the secondary polyethylene content.

Thus, the use of polyethylene-modified binder significantly enhances its adhesion to mineral materials, which positively affects the air void content and water resistance of asphalt concrete.

The longevity of road pavement is significantly influenced by its resistance to frost. Repeated freeze-thaw cycles can lead to the deterioration of asphalt concrete structure. As such, ensuring the structural integrity of stone mastic asphalt under the combined effects of moisture and temperature is essential for extending pavement lifespan. Within the pore spaces of asphalt concrete, water interacts with the surrounding materials. Due to its higher dielectric constant compared to the low-polarity nature of bituminous substances, water engages more actively with hydrophilic sites on the surface of mineral aggregates. Over time, this leads to the displacement of the bonds between bitumen components and the hydrophilic mineral surface through adsorption processes [15-16].

The findings (see Fig. 6) demonstrate that incorporating a binder modified with polyethylene has a beneficial impact on the water resistance of asphalt concrete. As the polyethylene content in the binder increases, the water resistance coefficient of the material also rises. At the same time, a notable reduction in air void content is observed in the asphalt concrete specimens. This results in a higher proportion of closed pores within the structure, which in turn enhances the frost resistance of the pavement. As noted in [12], a key indicator of the water resistance for both polymer-modified and conventional asphalt concrete is the long-term water resistance coefficient. To study the water resistance of bitumen emulsion samples modified with polymer waste (polyethylene), an additive containing various amounts of secondary polyethylene was used. Its concentration in the bitumen was 2%, 4%, 6%, 8%, and 10%. For comparison, PBV 60 polymer-bitumen emulsion was used.

It is known that the adhesion of the binder to the surface of the stone materials is a key factor affecting the water resistance of asphalt concrete. The better water resistance and lower water absorption of PBV samples on bitumen modified with secondary polyethylene can be attributed to the stronger adhesion of the modified binder to the mineral part of the asphalt concrete mixture. This facilitates more effective adhesion of the bitumen film to the surface of mineral aggregates, thereby increasing the water resistance of the modified bitumen emulsion. The enhanced bonding effect may also stem from structural alterations in the macromolecular chains of polyethylene. These assumptions are confirmed by the results of adhesion studies of the investigated binders to granite crushed stone (Fig. 7).

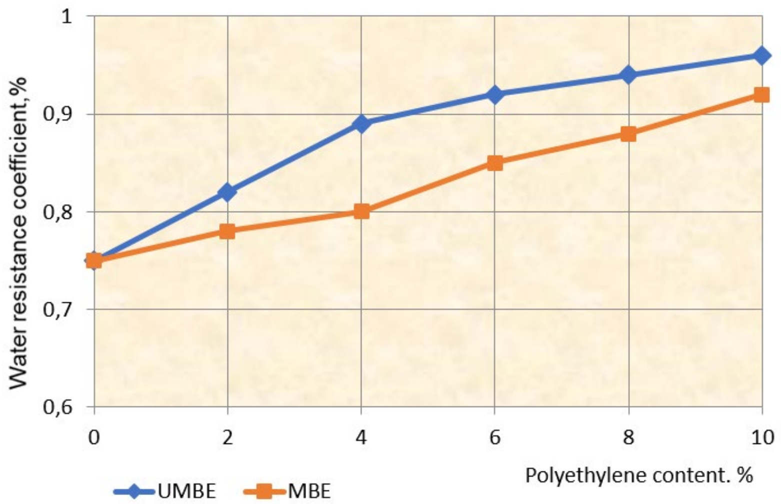


Fig. 7. Dependence of the air void content of asphalt concrete with modified bitumen emulsion on the amount of secondary polyethylene introduced.

As anticipated, the initial bitumen emulsion demonstrates noticeably lower adhesion properties compared to the emulsion modified with secondary polyethylene (Fig. 7), which can be attributed to the presence of active functional groups on the polyethylene surface. The adhesion characteristics are directly reflected in the water resistance performance. For instance, the modified specimens show a water resistance coefficient of 0.88, a value comparable to that observed in samples containing both secondary polyethylene and Kulantau vermiculite after 40 days of exposure.

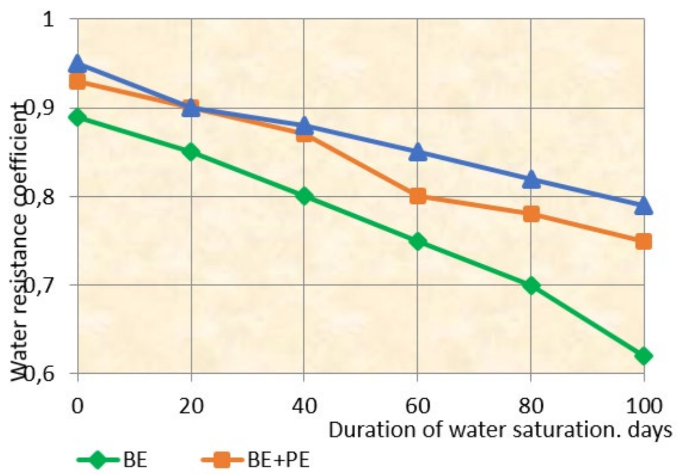


Fig. 8. Dependence of the water resistance coefficient of modified samples (BE+PE, BE+PE+KV) on the duration of water saturation.

Thus, the use of polyethylene-modified binder significantly enhances its adhesion to mineral materials, which positively affects the air void content and water resistance of asphalt concrete.

The effect of secondary polyethylene and vermiculite on increasing water resistance and stability of the asphalt concrete structure during alternate freezing and thawing.

The durability of the pavement largely depends on frost resistance [16-17]. Repeated cycles of freezing and thawing can lead to the deterioration of the asphalt concrete structure. Thus, maintaining the structural integrity of asphalt concrete under combined moisture and temperature stresses is essential for extending its service life (Fig. 8). Inside the pores of asphalt concrete, water interacts actively with the surrounding materials. Given its higher dielectric constant compared to the low-polarity constituents of bitumen, water forms stronger interactions with the hydrophilic sites on mineral surfaces. Prolonged water exposure leads to the gradual displacement of bonds between bitumen components and the mineral substrate's hydrophilic centers. In asphalt concrete saturated with moisture, fluctuations in temperature and alternating wetting and drying cycles generate internal stresses caused by water volume changes within the pores, in addition to the differences in thermal expansion coefficients among water, bitumen, and mineral aggregates. When these stresses reach critical values, the structural bonds within the asphalt concrete weaken, leading to its destruction under the impact of traffic loads [13]. Frost resistance tests were conducted on asphalt concrete samples containing 2%, 4%, and 6% secondary polyethylene. For comparison, asphalt concrete compositions with PBV that did not contain secondary polyethylene were used. As a criterion for frost resistance, the decrease in strength at 20°C and 50°C of asphalt concrete samples on modified bitumen was compared to the original composition.

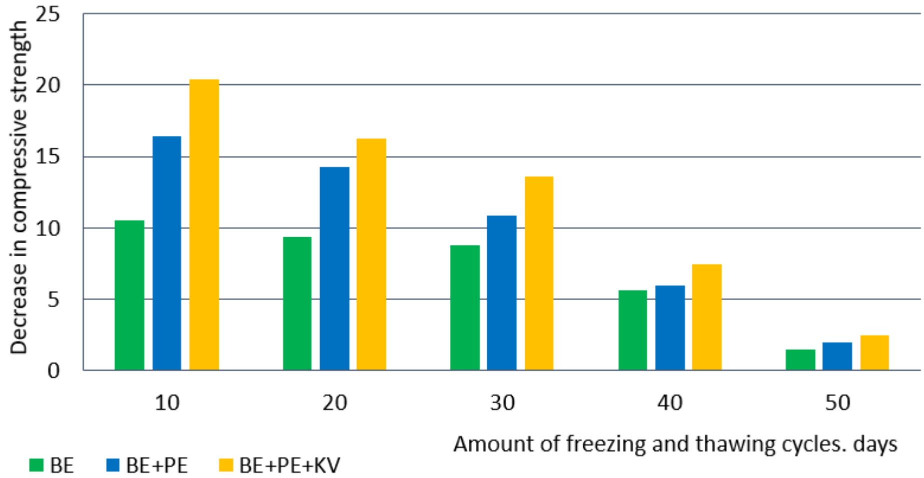


Fig. 9. Decrease in the strength of asphalt concrete with modifiers during alternate freezing and thawing.

From Fig. 9, it follows that the frost resistance of asphalt concrete increases by 56.19% with the introduction of secondary polyethylene into the bitumen emulsion (BE), and by an additional 24.39% with the addition of vermiculite. The decrease in compressive strength at 20°C after 10 freeze-thaw cycles was 10.5% for BE, 16.4% for PBE, and 20.8% for PBE with KV, while after 20 cycles, it was 9.4%, 14.3%, and 16.3%, respectively (Figure 8), and after 50 cycles – 1.5%, 2%, and 2.5%.

The frost resistance of asphalt concrete after 10 days of freeze-thaw cycles decreased by 16.4% to 6% for the sample with polyethylene, and by 20.4% to 7.5% for PBE containing additional vermiculite.

For the bitumen emulsion, the decrease in strength was 10.5% after the first 10 cycles, 9.4% after 20 cycles, and 5.6% after 50 cycles. The decrease in strength for asphalt concrete samples containing polyethylene after 10 freeze-thaw cycles was 16.4%, after 20 cycles – 14.3%, after 30 cycles – 10.9%, and after 50 cycles – 2%. These results indicate the higher durability of asphalt concrete with secondary polyethylene, which is quite logical. The decrease in compressive strength at 20°C significantly decreased with the introduction of Kulantau vermiculite into the composition, which improved the adhesion of the mixture. The adhesion process can be viewed as the adsorption of the bitumen emulsion on the surface of the mineral material. Adsorption occurs due to intermolecular interaction, and adhesion, accordingly, increases with the improvement of this interaction. This is achieved by increasing the activity of the bitumen emulsion through the introduction of additives with active functional groups.

Based on the conducted research and the data from the literature sources [7-10], requirements were formulated for modified bitumen emulsions obtained using standard bitumen (Table 6): 70/100. The recommended EKV content is 4% for petroleum bitumen.

Table 3. Technical requirements for polymer-bitumen emulsions with EKV based on petroleum bitumen.

Property	Value for polymer-bitumen emulsion with EKV based on petroleum bitumen
Appearance, color, visually	Viscous thermoplastic mass of dark brown color
Homogeneity, visually	Visually homogeneous
Softening point, °C (Ring and Ball method)	From 50 to 72
Ductility, cmat 25°C	Notlessthan 60
Brittleness temperature, °C	Not more than minus 22
Flash point in an open cup, °C	Not less than 200

4. CONCLUSION

A formulation of a polymer-bitumen emulsion was developed based on domestic materials and polymer waste, enabling the use of environmentally friendly and energy-efficient technologies in road construction.

A composition of polymer-bitumen emulsion based on domestic materials and polymer waste was developed, enabling the use of environmentally friendly and energy-saving technologies in road construction.

It was determined that incorporating secondary polyethylene as a bitumen modifier enhances the water and freeze-thaw resistance of asphalt concrete. This improvement is attributed to the polar molecules in secondary polyethylene, which actively bond with the mineral constituents of the asphalt concrete mix. Frost resistance tests of polymer-bitumen emulsion samples with secondary polyethylene showed increased durability with the addition of secondary polyethylene. These results indicate the higher resistance of asphalt concrete using polymer-bitumen emulsion, which is quite expected.

Polymer-asphalt composites formulated from bitumen emulsion and polyethylene demonstrate the highest durability against environmental moisture and temperature variations, which is related to the polymer's elevated basicity. This enhanced resistance will contribute to the asphalt concrete's ability to withstand the aggressive effects of water and low temperatures in road pavement.

It was found that the decrease in compressive strength of asphalt concrete samples using bitumen emulsion with secondary polyethylene after 10 freeze-thaw cycles was 16.4%, after 20 cycles – 14.3%, after 30 cycles – 10.9%, and after 50 cycles – 2%. These results confirm the greater durability of asphalt concrete with secondary polyethylene, which is quite logical.

The additional introduction of Kulantau vermiculite into the composition increases the adhesion of the polymer-bitumen composition and, as a result, decreases the loss of compressive strength at 20°C during alternate freeze-thaw cycles of asphalt concrete samples.

According to the findings of the study, the polymer-bitumen-vermiculite emulsion is designated for use as a bituminous emulsion in the repair of thermal joints and fissures in asphalt concrete pavements (with 4 ± 0.5 wt.% of expanded Kulantau vermiculite in the organic binder).

Thus, the use of secondary polyethylene, Kulantau vermiculite, and the EMBIT emulsifier in the composition of the modified bitumen emulsion ensures stable adhesion across a wide range of moisture and temperature conditions. It also increases the specific surface area, which gains additional energy capacity, leading to improved adhesion to bitumen, enhanced strength characteristics of asphalt concrete structures, and, as a result, the durability of asphalt concrete pavements under repeated freeze-thaw cycles is enhanced.

5. ACKNOWLEDGEMENTS

These studies were carried out with the support of the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (grant AP19679034“Development of technology for producing bitumen materials for the road industry with the disposal of polymer wastes in the technological process”).

REFERENCES

1. Bhupendra S., Praveen K. Effect of polymer modification on the ageing properties of asphalt binders: chemical and morphological investigation. Constr. Build. Mater. 205. 2019. P. 633 – 641. DOI: 10.1016/j.conbuildmat.2019.02.050
2. Yadykina V.V., Navolokina S.N., Gridchin A.M., The dependence of the modified bitumen properties on the amount of vinyl acetate in the sevilen composition. Mater. Sci. Forum. 974: 2019. P. 175 – 180. DOI: 10.4028/www.scientific.net/MSF.974.175
3. Cao G., Du T., Bai Y., Yang T., Zuo J. Effects of surfactant molecular structure on the stability of water in oil emulsion. Journal of Petroleum Science and Engineering. 196. 2021. DOI:10.1016/j.petrol.2020.107695
4. Sjadi S.El, Nederpel Q.A., Cotiuga I.M., Picken S.J., Besseling N.A.M., Mendes E., Lommerts B.J. BiopolymerScleroglucan as an Emulsion Stabilizer. Colloids and Surfaces A Physicochemical and Engineering Aspects. 2018. 546. P. 326 – 333. DOI:10.1016/j.colsurfa.2018.02.035
5. Shakharbayev K.A., Izmailova G.G., Sivokhina E.S. Opyt primeneniya sherohovatoj poverhnostnoj obrabotki s bitumnoj emul'siej [Experience for the use of rough surface treatment with bitumen emulsion]. Vestnik Kazahskoj akademii transporta i kommunikacij im. M. Tynyshpaeva. 2018. 2 (105). P. 244 – 251. DOI: 10.52167/1609-1817
6. Yadykina V.V., Navolokina S.N., Gridchin A.M. The dependence of the modified bitumen properties on the amount of vinyl acetate in the sevilen composition. Mater. Sci. Forum. 2019. 974. P. 175 – 180. DOI: 10.4028/www.scientific.net/MSF.974.175
7. Bulanov P., Vdovin E., Stroganov V., Mavliev L., Juravlev I. Complex modification of bituminous binders by linear styrene-butadiene-styrene copolymer and sulfur. Proceedings of STCCE. International Scientific Conference on Socio-Technical Construction and Civil Engineering 2022: Lecture Notes in Civil Engineering. Switzerland. 2022. P. 405 – 413. DOI: 10.1007/978-3-031-14623-7_35
8. Qudaybergenov A. Improving the quality of bitumen emulsion in road construction. Modern Science and Researc. 2024. 3 (2). P. 416 – 418. DOI:10.5281/zenodo.10651808
9. Mazurek G., IwańskiM., BuczyńskP., HorodeckaR. Influence of innovative three-element binder on permanent deformations in recycled mixtures with emulsion and foamed bitumen Archives of Civil and Mechanical Engineering. 2021. 21. P. 55. DOI:10.1007/s43452-021-00192-9.
10. Ming Liang, Shisong Ren, Weiyu Fan, Xue Xin, Jingtao Shi, Hui Luo. Rheological property and stability of polymer modified asphalt: effect of various vinyl acetate structures in EVA copolymers. Constr. Build. Mater. 2017. 137. P. 367 – 380. DOI: 10.1016/j.conbuildmat.2017.01.123
11. Galdina V.D. Modified Bitumens: Textbook, SibADI Publishing. Omsk. 2009. P. 230.
12. Yuliestyan A., García-Morales M., Moreno E., Carrera V., Partal P. Assessment of modified lignin cationic emulsifier for bitumen emulsions used in road paving. Materials and Design. 131. 2017. P. 242-251. DOI: 10.1016/j.matdes.2017.06.024.
13. Onishchenko A., Stolyarova L., Bieliatynskyi A., Evaluation of the durability of asphalt concrete on polymer modified bitumen. E3S Web Conf. 2020. 157. 06005. DOI: 10.1051/e3sconf/202016403027.
14. Strokova V.V., Markova I.Y., Dmitrieva T.V., Shiman A.A. The influence of fly ashes from power plants on rheological properties of bitumen binder. Journal of Fundamental and Applied Sciences. 2016. 8 (2S). P. 1487 – 1498. DOI: 10.4314/jfas.v8i2s.293.2

15. Mignini C., Cardone F., Graziani A. Experimental study of bitumen emulsion-cement mortars: mechanical behavior and relation to mixtures. Materials and structures. 2018. 5 (6). 149. DOI: 10.1617 / s11527-018-127
16. Omar H.A., Yusoff N.I.M., Mubaraki M., Ceylan H., Effects of moisture damage on asphalt mixtures. J. Traffic Transp. Eng. (Engl. Ed.). 2020. 7 (5). P. 600 – 628. DOI: 10.1016/j.jtte.2020.07.001
17. e W., Jiang W., Li P., Yuan D., Shan J., Xiao J. Analysis of mechanism and time-temperature equivalent effects of asphalt binder in short-term aging, Constr. Build. Mater. 2019. DOI: 10.1016/j.conbuildmat.2019.04.197
18. Markov A.Yu., Strokova V.V., Bezrodnykh, A.A., Stepanenko M. Properties of fuel ashes of various types as components of bitumen emulsion. Building and reconstruction. 2020. 88. P. 67 – 76. DOI: 10.33979/2073-7416-2020-88-2-67-76
19. Rupal A., Sharma S.K., Tyagi G.D. Experimental investigation on mechanical properties of polyurethane modified bituminous waterproofing membrane. Materials Today: Proceedings. 27. 1. 2020. P. 467 – 474. DOI.org 10.1016/j.matpr.2019.11.278.
20. Bezrodnykh A.A., Strokova V.V., Markova I.Yu., Potapov D.Yu. Bitumen emulsions for road construction purposes, modified by fly ash. Stroitel'nye Materialy [Construction Materials]. 2021. 11. P. 59 – 66. DOI: https://doi.org/10.31659/0585-430X-2021-797-11-59-66
21. Kaldybekova Zh.B., Syrmanova K.K., Kovaleva A.Y., Polyfunctional Sorbents. Typography "Alem". Shymkent. 2018. P. 174.
22. Syrmanova K., Kaldybekova Zh., Agabekova A., Baizhanova S. Influence of the chemical composition of Kulantau vermiculite on the structure of modified bitumen compositions. J. Compos. Sci. 2024. 8 (4). P. 118. DOI: 10.3390/jcs8040118
23. Methodological recommendations for the use of emulsifiers for bitumen emulsions "EMBIT". Available at: https://propitki38.ru/wp-content/uploads/2023/02/2022-metodicheskie-rekomendaczii-emulgator-embit-bs.pdf
24. Garipov A.R., Makarov D.B., Khozin V.G., Stepanov S.V. Finely dispersed bitumen emulsion for the modification of cement concrete for road use. Construction and Geotechnics. 2022. 13 (3). P. 85 – 97. DOI: 10.15593/2224-9826/2022.3.08
25. Antonova I.I., Ayupov D.A., Khakimullin Y.N., Khozin V.G. Bitumen emulsions for waterproof and roof coverings. News KSUAE. 2023. 2. 1 (63). P. 6 – 14. DOI: 10.52409/20731523_2023_1_6

INFORMATION ABOUT THE AUTHORS

Syrmanova K.K., e-mail: syrmanova.kulash@mail.ru, ORCID ID: https://orcid.org/0000-0002-1468-6440; SCOPUS: https://www.scopus.com/authid/detail.uri?authorId=56389533000, M. Auezov South Kazakhstan University, Doctor of Technical Sciences, Professor of the Department of Technology of Inorganic and Petrochemical Industries

Tuleuov R.M., e-mail: tuleuov_rassul@mail.ru, ORCID ID: https://orcid.org/0009-0004-6450-4686., SCOPUS: https://www.scopus.com/authid/detail.uri?authorId=59008925000, M. Auezov South Kazakhstan University, Doctoral Student of the Department of Technology of Inorganic and Petrochemical Industries

Kaldybekova Zh.B., e-mail:zkaldybekova@mail.ru, ORCID ID: https://orcid.org/0000-0003-2906-9098; SCOPUS: https://www.scopus.com/authid/detail.uri?authorId=57193564121, M. Auezov South Kazakhstan University, Candidate of Technical Sciences, Associate Professor of Chemical Technology

Baizhanova Sh.B., e-mail: bshb86@mail.ru, ORCID ID: https://orcid.org/0000-0003-4286-7369; SCOPUS: https://www.scopus.com/authid/detail.uri?authorId= 59329730500, M. Auezov South Kazakhstan University, Master's Degree, Senior Lecturer

Kolesnikova O.G., e-mail: ogkolesnikova@yandex.kz, ORCID ID: https://orcid.org/0000-0001-6871-8367; SCOPUS: https://www.scopus.com/authid/detail.uri?authorId= 57210585138, M. Auezov South Kazakhstan University, Master of Engineering and Technology

Zhumayev Zh.Zh., e-mail: zholdybay.zhumayev@yu.edu.kz, ORCID ID: https://orcid.org/0000-0002-2866-3231; SCOPUS: https://www.scopus.com/authid/detail.uri?authorId=57321186500, M.Sh. Yesenov Caspian University of Technology and Engineering, Professor

Nigmetov M.Zh., e-mail: mermurat.nigmetov@yu.edu.kz, ORCID ID: https://orcid.org/0000-0002-8075-8828; SCOPUS: https://www.scopus.com/authid/detail.uri?authorId=57220583878, M.Sh. Yesenov Caspian University of Technology and Engineering, Associate Professor

Yesbolay G.I., e-mail: gulbanu.yesbolay@yu.edu.kz, ORCID ID: https://orcid.org/0000-0001-5072-833X; SCOPUS: https://www.scopus.com/authid/detail.uri?authorId=57369750400, M.Sh. Yesenov Caspian University of Technology and Engineering, Master's Degree, Senior Lecturer