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# CURRENT STATE OF THE METHODS FOR DETERMINING THE ADHESIVE AND COHESIVE PROPERTIES OF ROAD BITUMEN

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**Abstract.** *Introduction*. The sphere of transport infrastructure is developing rapidly, which underlines the importance of stable properties of bitumen in the construction of road surfaces. A necessary condition for improving the quality of the bitumen binder is its high adhesion to the surface of the mineral filler. The adhesion of bitumen with mineral filler is an important indicator that characterizes the quality of the asphalt concrete mixture, the performance characteristics of the asphalt concrete coating and its resistance to damage. An adequate assessment of these characteristics becomes a key factor in ensuring the durability and reliability of road surfaces. The article analyzes the current state of methods for determining the adhesive and cohesive characteristics of bitumen and mineral filler. *The aim* of the work is a thorough analysis of various methods used to evaluate the adhesive and cohesive properties of bitumen, with subsequent identification of their advantages and disadvantages. An overview of both traditional and modern approaches used to determine these characteristics is given to better understand the structure and behavior of bituminous materials. *Conclusion*. The article emphasizes the need for further research and development in the field of methods for determining the adhesive and cohesive properties of bitumen, considering modern requirements for road infrastructure. It is necessary to develop scientific and practical approaches to improving existing regulatory documents considering the characteristics of bituminous materials. It can be concluded that it is necessary to develop new accurate reproducible methods using computer technologies that automate data collection and processing and reduce the likelihood of errors.

**Keywords:** asphalt concrete, bitumen-aggregate adhesion, adhesion, cohesion, surfactants, dispersed particles, adsorption, adhesion promoters, adhesion testing methods

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## 1. Introduction

The quality of the road surface has a significant impact on the infrastructure and society. The degree of development of road transport at the current time is associated with a continuous increase in the proportion of cargo transportation, the intensity of vehicle traffic, which leads to an increase in dynamic loads on the road surface. Intensive workload has a direct impact on the untimely destruction of road surfaces, caused by rapid deterioration and the formation of cracks and voids on the asphalt concrete surface. The combination of these factors determines the necessity to improve the quality of asphalt concrete coatings, by achieving high physical and mechanical characteristics of asphalt concrete, to ensure its stability [1-3].

Bitumen is a binder of the asphalt concrete combination. The necessary condition for improving the quality of the bitumen binder is a high adhesion to the surface of the mineral filler, plasticity and stability of properties under the conditions of a wide temperature range, resistance to cracking [4].

The quality of bituminous binder can vary, depending on the ratio of various components that make up the petroleum fraction. Petroleum dispersive systems (PDS) are described in the works of many researchers – Rebinder P.A., Gun R.B., Kolbanovskaya A.S. and others [4-10]. According to their views, petroleum bitumen is polydisperse systems, with oils and tars as the dispersion medium, and asphaltenes and high-molecular-weight paraffins as the dispersed phase. The ratio of the chemical groups in the composition of bitumen determines its dispersive structure and rheological behavior, thus influencing its physicochemical and operational properties.

As the oil sector undergoes changes, this affects the quantity, price and quality of bitumen, which affects the composition of residues used in bitumen road surfaces. Since more than 90% of the world's road network consists of bitumen coatings, changes in the supply of bitumen affect the design of these coatings[11]. To produce road bitumen, heavy oils with a high content of resinous substances and a low content of paraffin fractions are most suitable. A high content of asphaltenes increases the hardness, softening temperature, and brittleness of the bitumen, whereas predominance of oils in the composition makes the bitumen soft and easily fusible. The elasticity of bitumen increases with the increasing content of petroleum resins [4, 10]. Road bitumen is represented by grades such as BND 200/300, BND 130/200, BND 90/130, BND 60/90, BND 40/60, BN 200/300, BN 130/200, BN 90/130, BN 60/90 [12-13].

The adhesive characteristics of bitumen largely depend on the nature of the main components that affect the performance characteristics of the asphalt concrete mixture. Oxidized road bitumen, as a rule, has anion-active functional groups of an acidic nature, due to which they are well sorbed on the surface of the mineral filler, which has a basic character [4, 15]. Acidic minerals containing more than 65% $SiO_2$ do not form lasting chemisorption bonds when interacting with bitumen. This is due to the presence of active adsorption centers such as

Lewis and Brensted, which determine the activity of the mineral filler in relation to the binder and the ability to provide strong adhesive bonds [15].

The fractional composition plays an equally important role in the quality of adhesion to the filler: the smaller filler particles exceed the corresponding large fillers in the quality of adhesion to the bitumen binder. With an increase in the dispersion of the material, its activity increases, which corresponds to an increase in the volume of the structured bitumen in the boundary layers [16].

The destruction of the road surface can be caused by several specific factors. As mentioned above, it can be attributed to unsatisfying characteristics of the mineral filler (acidic nature, small contact area), as well as the insufficient quality of the bituminous binder used in the asphalt production. The main supplier of bitumen in Kazakhstan is Russia, wherefrom over 300 thousand tons of road bitumen are imported annually. In Kazakhstan, however, the annual domestic production of bitumen does not exceed 70 thousand tons per year. It should also be noted that the quality of imported bitumen does not always meet the requirements of modern road construction in the country, characterized by a variety of road-climatic zones [17]. In multiple oil refineries, the technical infrastructure remains at a low level: the facilities are not equipped with modern-type oxidation columns, and outdated tubular reactors continue to be used. These and many other factors lead to an uncontrolled variability in the quality indicators of the raw materials entering processing, which, in turn, significantly influences the quality of the produced bitumen [18-20].

## 2. Modification of bitumen

In both domestic and global practices, varied types of modifiers are extensively used to impart improved properties to bitumen. It is worth noting that when using high-quality bituminous binders and a well-composed recipe for asphalt concrete combination, the road-paving material can be reliable even without the use of modifying additives [18, 23].

The main requirement for a modifying additive is economic efficiency, particularly general availability and cost-effectiveness [24]. From a technical standpoint, to create composite materials based on bituminous binders with a defined set of characteristics, only such modifiers are necessary, which meet the following conditions:

– stability over a wide temperature range, including during the preparation temperature of the asphalt concrete mixture;

– compatibility with bitumen during the preparation of the mixture of bituminous binder with mineral filler;

– provision of the properties of the road surface such as resistance to shear stresses, stiffness, and resistance to sharp temperature fluctuations;

– chemical and physical stability during storage, processing, as well as in real operating conditions as part of the road surface.

The scientific research on the modification of bitumen, using secondary products, is widely known. The research [25-29] considers the effect of cellulose-

stabilizing additives on the physical and mechanical characteristics of bitumen. As a result of the conducted studies of the bitumen samples with stabilizing additives of various nature, it has been found that cellulose-containing additives in the composition do not significantly change the properties of the binder, and the presence of surfactants in the samples, on the contrary, affects the thixotropic properties of bitumen. These additives increase the hardness and increase the softening temperature of the binder, which, in turn, indicates an improvement in the performance characteristics of bitumen and the possibility of operation in a wide temperature range [26].

It is believed that one of the promising directions for improving the quality of asphalt concrete pavement is the use of sulfur [30-34]. The demand for the use of technical sulfur as a modifying additive is due to its cheapness, and it is produced in large volumes as a by-product in various fields of the chemical industry. The world experience in the field of road construction indicates an increase in the physical-mechanical and rheological properties of sulfuric acid bitumen binders and mixtures based on them in comparison with conventional bitumen and asphalt concrete. Modification of bitumen for asphalt concrete with sulfur implies the introduction of additives or modifiers using sulfur into the bitumen. These modifiers can improve various properties of bitumen and, consequently, improve the characteristics of asphalt concrete. For example, the addition of sulfur can improve the adhesion of bitumen to mineral fillers, increase resistance to thermal effects and improve the fatigue resistance of the material. A significant problem in the production of sulfur bitumen binders is the formation and release of toxic compounds when heating bitumen with sulfur.

It is proved that the modification of the rubber crumb improves the properties of pure bitumen [35-40]. In the presented scientific articles, there are decreases in the penetration rate of bitumen modified with rubber chips compared to the initial one, which indicates an increase in the viscosity of the system, the reason for which, most probably, is the adsorption of part of the light oil fractions with rubber swarf. In the case of modified rubber crumbs, the absorption of light oil fractions in the bitumen composition occurs to a lesser extent. The interaction of bitumen with a rubber modifier is accompanied by two processes: swelling of the rubber powder, followed by an increase in its mass, and leaching of the ingredients, soluble in the bitumen medium from the rubber with a decrease in the mass of the modifying additive. The heat resistance of the binder also increases. A distinctive feature of bitumen-rubber compositions in comparison with unmodified bitumen is elasticity, which can also be said about polymer-bitumen compositions, where the polymer is completely dissolved in a bitumen binder. Despite several advantages, the use of rubber crumbs as a modifier has disadvantages. The use of rubber crumbs can cause difficulties when processing it and adding it to bitumen. This requires additional equipment and technological changes in the production process. Since rubber crumb is a relatively new material in this field, additional research is required to fully understand its impact on the long-term properties of asphalt concrete and road surfaces. However,

despite these disadvantages, the rubber crumb continues to attract attention and research, since its use can help in solving problems with waste disposal and improving the environmental performance of road construction.

Among all methods of improving the quality of road bitumen, the use of polymers seems to be one of the most promising. Modification of bitumen, using polymer additives, makes it possible to increase resistance to shear stress and cracking, and increases the service life of asphalt concrete road surfaces [41-46]. For this reason, the use of polymer-bitumen modifiers in road construction, despite their high cost, is considered economically justified. The most common polymer modifiers used in road construction are thermoplastics, elastomers and thermoplastics. If we consider the class of plastomers (thermoplastics), polyolefins have been one of the first modifiers [47-50]. Among polyolefins, polyethylene and polypropylene are of increased interest. For the construction of highways, it is polyethylene that is most widely used [50], for example, high- and low-density polyethylene (HDPE and LDPE), isotactic polypropylene, atactic polypropylene, etc. Polymers of several polyethylene began to be used as a modifying additive for bitumen based on several advantages, such as an increase in the viscosity of the binder and a decrease in sensitivity to high temperatures. However, despite the positive characteristics of the modified bitumen, there is its instability under long-term storage conditions and the need for constant mixing, which limits the use of polyethylene as a bitumen modifier, as a result [51].

From several plastomers, ethylene copolymers are used when modifying bitumen [44, 52] – these are polymers such as ethylene-vinyl acetate (EVA) and ethylene-butyl acetate (EBA). In such polymers, the mechanical properties are determined by the content of vinyl acetate. The low content of vinyl acetate in the polymer makes it similar in properties to low-density polyethylene. An increase in the content of vinyl acetate increases transparency, flexibility, the ability to mix and stitch, but at the same time increases the adhesion and hardness of the raw material, the softening temperature of the modified binder decreases. Even though improving the properties of bitumen, using plastomers as a modifier has several advantages, there are significant disadvantages that limit their use. The main limitation is not the ability to improve the elastic recovery of polymer-bitumen binder, as well as the susceptibility to aging.

Another class of polymers, used to improve the quality of asphalt concrete mixtures, are elastomers [42, 52, 53]. The most significant representatives of elastomers are rubbers, both natural and synthetic. The need to use industrial volumes of elastomers contributed to the complete transition to synthetic rubbers. The use of synthetic rubbers as modifiers increases the extensibility and elasticity of bitumen increase its resistance to cracking and temperature changes. Divinyl Styrene Rubber (DSR) is now increasingly used as a modifying additive for asphalt concrete coatings. It has been found [54-58] that the addition of DSR to the bitumen binder increases the adhesive properties of the composite material and significantly improves adhesion to the mineral components of asphalt concrete. It seems optimal to use a 7% divinyl styrene rubber additive in bitumen.

However, it is important to note that the effectiveness of rubber modification may depend on specific operating conditions, the type of rubber, its content and other factors. It is best to use a modification of rubber in accordance with technical standards and recommendations of the road construction industry.

One of the most promising and most frequently used classes of industrial polymers in the road industry is thermoplastic elastomers (thermoplastics) [56]. Due to their structure, they combine the properties of both thermoplastics and elastomers. Among them, styrene-butadiene-styrene (SBS) and styrene-ethylene-butylene-styrene (SEBS) thermoplastic elastomers have become widespread and are of the greatest interest to researchers. According to the information from various sources [58, 59], the addition of thermoplastic elastomers, in addition to improving the elasticity and extensibility of the binder, contributes to the hardening of the material mainly by improving the cohesive properties of bitumen. The cohesion of bitumen binders characterizes the shear resistance of the connecting layers at the molecular level. This property, along with adhesion and viscosity, is the main indicator that gives an objective idea of the mechanical properties of organic binders at high temperatures.

The quality and durability of asphalt concrete coatings, as mentioned earlier, largely depends on the adhesion of the bitumen binder of the mineral filler. Road bitumen in its composition contains surfactants, which, as a rule, are represented by asphalt genic acids and their anhydrides and provide satisfactory adhesion of bitumen with mineral filler. In case of their insufficient quantity in the binder composition, surfactants modifiers of asphalt concrete mixture are used to improve the quality of bitumen adhesion to the filler [58-66]. The mechanism of action of surfactants in a bitumen dispersion medium is based on the processes of their adsorption on the hydrophilic surface of the filler. At the same time, a decrease in surface tension, wetting of the surface is caused by a fixed orientation of the surfactant molecules of the polar group to the surface of the solid phase, and by a hydrocarbon radical into the hydrocarbon medium [60]. An improvement in wetting entails an improvement in adhesion in accordance with the combined Dupre-Young equation [61]. This effect is greater the higher the amount of adsorption of surfactants on the filler surface and reaches the greatest value when they are chemisorbed.

Nitrogen-containing chemical compounds are promising adhesive additives for bitumen, providing improved adhesion and resistance of road surfaces to destruction.In road construction, cationic, nonionic and anionic surfactants can be used in the manufacture of asphalt concrete mixtures. The most effective adhesive additives are cationic additives [62, 67-69], based on nitrogen-containing chemical compounds, such as imidazolines, amidoamines and amines. Most domestic and foreign companies strive to produce adhesive additives based on nitrogen-containing chemical compounds, namely imidazolines, since asphalt concrete mixtures with the addition of this type of modifier are characterized by a high coefficient of water resistance and increased adhesion of bitumen with mineral filler, which allows the road surface to maintain its performance

characteristics when exposed to adverse conditions. However, the widespread introduction of cationic adhesive additives into the practice of road construction is constrained by limited production capabilities and a shortage of raw materials, respectively, their high price.

The lack of own manufacturers of a wide range of modifying additives leads to the need to import them from foreign countries, which significantly increases the cost of bitumen materials. The presence of petrochemical waste on a large scale makes it possible to produce cheap, effective and competitive modifying additives [70, 71]. Additives obtained from industrial waste, including oil refining industry, can be used as modifiers for asphalt concrete mixtures. The use of such surfactants has several advantages, such as reducing the cost of production and waste disposal.

**3. Methods of bitumen adhesion and cohesion determination**

In this connection, given the importance of the adhesive-cohesive properties of bitumen in the formation of a high-quality asphalt concrete coating, it is necessary to properly assess these properties. Both qualitative and quantitative methods are used to find the indicators of bitumen adhesion to the filler [41, 71-75]. The most common qualitative (visual) method of determination in accordance with Interstate Standard 11508-74. The essence of this technique is a visual assessment of the degree of coating of mineral filler with bitumen after its boiling in water and comparison with the reference samples. The adhesion of bitumen to the filler based on this method is determined by the characteristics of the bitumen film on the surface of the mineral filler and is estimated in points (from 2 to 5). High-quality bitumen is characterized by the complete preservation of the bitumen film of the filler surface at the end of testing, while in some places the film may be reduced in places. This method has its drawbacks and, first, it is the subjectivity of the visual assessment, which depends on the individual perception of the expert. In [63], based on the methodology of qualitative determination of adhesion, a quantitative method was proposed in which the adhesion coefficient is calculated as the ratio of the mass of bitumen in a bitumen-mineral mixture after boiling and drying to the mass of bitumen in a bitumen-mineral mixture before boiling. However, during the experiment [76] it has been found that because of testing, samples with the same adhesion indicators may visually differ from each other in the degree of coating of the mineral filler with a bitumen binder. In this regard, a decrease in the surface area of the mineral material is a more significant indicator and for this reason the gravimetric method is not recommended for assessing adhesion.

The author Kolbanovskaya A.S. describes a quantitative method for determining adhesion, which is based on the ability of mineral filler particles to adsorb polar molecules of methylene blue dye, and on a radioactive method for measuring selective adsorption of divalent metal salts. The disadvantage of this method is its high cost and duration of measurements (1.5-2 hours) [77].

As mentioned earlier, the adhesive properties of bitumen directly depend on the polarity of the components in its composition, including surfactants. Thus, the dielectric permittivity, which characterizes the force of the interaction between charges in a medium with respect to vacuum, can be attributed to the quantitative method of determining adhesion. Dielectric properties are studied in constant and alternating electric fields [78, 79].

It is possible to quantify the adhesion of bitumen to a mineral material based on an assessment of its wetting properties and finding the work of adhesion [60, 70, 79, 80-82]. The essence of the method consists in measuring the edge angle of wetting during the spreading of a drop of bitumen on the surface of a mineral material in a certain temperature range and finding the adhesion work through these values. The larger this value is, the better the adhesion of bitumen with mineral material will be. With an increase in the temperature of the substrate, wetting with bitumen proceeds much more efficiently, the work of adhesion increases. This is due to a decrease in viscosity, which improves the adhesion of bitumen with mineral filler and ensures a tighter fit of bitumen to the filler. The method for determining the adhesion of bitumen to the filler based on its wetting ability is the most informative in comparison with the standard qualitative methods for determining adhesion. Its advantage lies in the quantitative determination of the adhesion work, which makes it more objective.

Separately, it is worth mentioning the devices for determining the adhesive-cohesive properties of bitumen, which make it possible to obtain accurate and reliable results that can be used for product quality control, designing new materials and improving existing technologies. The most common method of finding the adhesive properties of bitumen is penetration [83-85]. Bitumen penetration is one of the methods of measuring the consistency or viscosity of bitumen at normal temperatures. The penetration procedure involves piercing the bitumen surface with a standard cone-shaped tool and measuring the penetration depth. The found indicators are divided into standards, which in turn are divided into brands. According to the brand, it is possible to determine the scope of bitumen application and its quality indicators. The depth of penetration of the needle (penetration) at 25°C characterizes the plasticity and viscosity of the binder, its technological properties. The higher the viscosity, the less penetration of the needle into the bitumen. Penetration is an important tool for engineers and manufacturers of bitumen materials, helping to determine their suitability for specific climatic conditions and requirements of road construction.

In addition to the above methods, the adhesion of bitumen can be determined by a separation test [12]. The essence of the method is to determine the effort that is spent on peeling (tearing off) the protective coating of certain geometric dimensions, carried out at an angle of 90° or 180°. In this case, measuring devices such as a dynamometer or a digital adhesive meter of the AMC 2-20, AMC 2-50 type with a division price of no more than 0.1 N (0.01 kgf) can serve as a means of controlling the adhesion value 12. The method makes it possible to identify a stable peeling force, which makes it possible to visually determine the nature of

the destruction of the material. Based on the method of determination of separation, the destruction of the material under study may be adhesive, cohesive or mixed in nature.

Cohesion, as well as adhesion, depends on several factors, including the nature of the substance, layer thickness and temperature. The mechanism of cohesion depends more on the viscosity and is determined by intermolecular forces and the structure of the bitumen material. The higher the cohesion, the better the resistance of the composite material to water. To date, the existing methods for determining the cohesive strength of bitumen binder can be divided into two main groups. In the first of them, the ability of the binder to hold the grains of mineral material on the surface of the asphalt concrete coating is evaluated. In this group, for bitumen used for surface treatment, the methods for determining adhesion simulate the tearing forces that arise under the action of a car wheel [86-87]. The most well-known of these methods are the pendulum method for determining the adhesion of Vialit in accordance with EN 13588-2008 [88], the method for determining the adhesive ability of bitumen emulsion - a test for adhesion to matte marble [89]; the method for determining the adhesive or cohesive separation of the bitumen layer from the surface of the stone material - a test for the adhesion strength of bitumen [90].

Another group of methods is related to the determination of the cohesive characteristics of the binder as a component of asphalt concrete. This group includes tests adapted for the assessment of cohesion: plasticity (EN 13589, EN 13398), direct stretching by the method. There are also developments [91], initially aimed at determining the cohesion of bitumen. With the help of a shear cohesiometer, it becomes possible to determine such characteristics of bitumen as fluidity and shear viscosity of the material. [92]. When working with a shear cohesiometer, the first step is to prepare samples of bitumen films having a strictly fixed thickness. During the preparation of the samples, 28.8 mg of bitumen is subjected to deformation between two working films under the influence of a load until a spot with a diameter of 12 mm is formed. Although this method is quantitative, it is quite complex and has a high probability of errors due to the use of small quantities. It gives an idea of the adhesive properties of bitumen based on changes in its viscosity when exposed to elevated temperatures. The main disadvantages of this device include the difficulty in ensuring the parallelism of the test plates, which could lead to a decrease in the accuracy of the results obtained and their significant dispersion. In addition, the disadvantages of this device can be attributed to the test mode with a constant loading speed.

Among modern cohesiometers, the most popular is the QCD-1 cohesiometer used in HNADU, as well as the plane-plane cohesiometer produced by BiRoI (USA), in which glass plates are used as substrates [93].

Among the measuring devices for determining the quality of bitumen for road construction, in addition to a penetrometer, an adhesive meter and a cohesiometer, a pendulum device can also be noted, which is designed to analyze the cohesion of road bitumen [94-96]. The device has a metal block that is bonded

to the holder by a layer of analyzed bitumen. The block is installed in the path of the "standard" pendulum, which has a hammer-shaped head. The lower the lifting height of the pendulum, the stronger the adhesion of bitumen. The method of determining the cohesion of bitumen, using a pendulum device is based on the measurement of the angle of the lifting of the pendulum after its collision with the block, the values of which make it possible to calculate the amount of cohesion of the tested binder. The EN 13588 standard requires the use of a pendulum device to determine the quality of bitumen and assign it the CE marking [97].

There are several modern methods for determining the adhesive and cohesive properties of bitumen and asphalt concrete. Some of them involve the use of specialized devices and techniques.

There are several modern methods for determining the adhesive and cohesive properties of bitumen and asphalt concrete. One of the methods that has recently been increasingly mentioned in scientific publications is the Method of atomic force microscopy (AFM) and scanning electron microscopy (SEM) [98-101]. These methods make it possible to visualize and study the structure and surface of materials, including adhesion between particles and layers.

In contrast to the current system for predicting the operational properties of asphalt concrete, based on measuring its strength characteristics at different temperatures, the quality of asphalt mixtures primarily depends on the properties of the bitumen binder. Therefore, it is necessary to develop scientific and practical approaches to improve the existing regulatory documents, considering the characteristics of bitumen materials. Based on the stated technological and methodological aspects of the study of the adhesive-cohesive properties of asphalt concrete coatings, it can be stated that it is necessary to develop new accurate reproducible methods, using computer technologies that allow automating data collection and processing, which reduces the likelihood of errors related to the human factor

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**ЖОЛ БИТУМЫНЫҢ АДГЕЗИЯЛЫҚ ЖӘНЕ КОГЕЗИЯЛЫҚ ҚАСИЕТТЕРІН АНЫҚТАУ ӘДІСТЕРІНІҢ ҚАЗІРГІ ЖАҒДАЙЫ**

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**Түйіндеме.** *Кіріспе*. Көлік инфрақұрылымының саласы қарқынды дамып келеді, бұл жол төсемдерін салу кезінде битумның тұрақты қасиеттерінің маңыздылығын көрсетеді. Битумды байланыстырғыштың сапасын жақсартудың қажетті шарты оның минералды толтырғыштың бетіне жоғары адгезиясы болып табылады. Минералды толтырғышпен битумның адгезиясы асфальтбетон қоспасының сапасын, асфальтбетон жабынының пайдалану сипаттамаларын және оның зақымға төзімділігін сипаттайтын маңызды көрсеткіш болып табылады. Бұл сипаттамаларды оңтайлы бағалау жол төсемдерінің беріктігі мен сенімділігін қамтамасыз етудің негізгі факторына айналады. Мақалада битум мен минералды толтырғыштың адгезиялық және когезиялық сипаттамаларын анықтау әдістерінің қазіргі жағдайы талданады. *Жұмыстың мақсаты*-битумның адгезиялық және когезиялық қасиеттерін бағалау үшін қолданылатын әртүрлі әдістерді мұқият талдау, содан кейін олардың артықшылықтары мен кемшіліктерін анықтау. Битуминозды материалдардың құрылысы мен әрекетін жақсы түсіну үшін осы сипаттамаларды анықтауда қолданылатын дәстүрлі және заманауи тәсілдерге шолу жасалады. Битумның адгезиялық және когезиялық сипаттамаларын анықтаудың жоғары дәлдігін қамтамасыз ететін құрылғылардың әртүрлі түрлері зерттелді. Мақалада деректерді тереңірек талдау үшін компьютерлік модельдеуді қолдану мүмкіндігі қарастырылады, бұл әртүрлі жағдайларда битумның әрекетін болжаудың жаңа перспективаларын ашады. *Қорытынды*. Мақалада жол инфрақұрылымына қойылатын заманауи талаптарды ескере отырып, битумның адгезиялық және когезиялық қасиеттерін анықтау әдістері саласындағы қосымша зерттеулер мен әзірлемелердің қажеттілігі көрсетілген. Асфальтбетонның беріктік сипаттамаларын өлшеу негізінде оның пайдалану қасиеттерін болжау жүйелері қолданыстағы әдістерді жетілдіруді талап етеді. Осы сипаттамаларды өлшеудің нақты әдістерінің болуы жол материалдарының сапасын жақсартудың негізі ғана емес, сонымен қатар үнемі өзгеріп отыратын климаттық және пайдалану факторлары жағдайында көлік желілерін тиімді жоспарлауға және күтіп ұстауға ықпал етеді. Сондықтан битуминозды материалдардың сипаттамаларын ескере отырып, қолданыстағы нормативтік құжаттарды жетілдірудің ғылыми және практикалық тәсілдерін әзірлеу қажет.

**Түйінді сөздер:** асфальтбетон, битумның агрегатқа адгезиясы, адгезия, когезия, беттік белсенді заттар, дисперсті бөлшектер, адсорбция, адгезия күшейткіштері, адгезияны сынау әдістері

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## СОВРЕМЕННОЕ СОСТОЯНИЕ МЕТОДОВ ОПРЕДЕЛЕНИЯ АДГЕЗИОННЫХ И КОГЕЗИОННЫХ СВОЙСТВ ДОРОЖНОГО БИТУМА

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**Резюме**. *Введение*. Сфера транспортной инфраструктуры быстро развивается, что подчеркивает важность стабильных свойств битума при строительстве дорожных покрытий. Необходимым условием улучшения качества битумного вяжущего является его высокая адгезия к поверхности минерального наполнителя. Адгезия битума с минеральным наполнителем является важным показателем, характеризующим качество асфальтобетонной смеси, эксплуатационные характеристики асфальтобетонного покрытия и его устойчивость к повреждениям. Адекватная оценка этих характеристик становится ключевым фактором обеспечения долговечности и надежности дорожных покрытий. В статье анализируется современное состояние методов

определения адгезионных и когезионных характеристик битума и минерального наполнителя. *Целью работы* является тщательный анализ различных методов, используемых для оценки адгезионных и когезионных свойств битума, с последующим выявлением их преимуществ и недостатков. Дается обзор как традиционных, так и современных подходов, используемых для определения этих характеристик, чтобы лучше понять структуру и поведение битуминозных материалов. Были изучены различные типы устройств, которые обеспечивают более высокую точность определения адгезионных и когезионных характеристик битума. В статье освещается возможность использования компьютерного моделирования для более глубокого анализа данных, что открывает новые перспективы в прогнозировании поведения битума в различных условиях. *Заключение*. В статье подчеркивается необходимость дальнейших исследований и разработок в области методов определения адгезионных и когезионных свойств битума с учетом современных требований к дорожной инфраструктуре. Системы прогнозирования эксплуатационных свойств асфальтобетона на основе измерения его прочностных характеристик требуют совершенствования существующих методов. Наличие точных методов измерения этих характеристик является не только основой для повышения качества дорожных материалов, но и способствует более эффективному планированию и обслуживанию транспортных сетей в условиях постоянно меняющихся климатических и эксплуатационных факторов. Поэтому необходимо разработать научные и практические подходы к совершенствованию существующих нормативных документов с учетом характеристик битуминозных материалов.

**Ключевые слова:** асфальтобетон,адгезия битума к заполнителю, адгезия, когезия, поверхностно-активные вещества, дисперсные частицы, адсорбция, усилители адгезии, методы испытания адгезии

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## References

1. Korenevsky V.V., Knyshov A.A., Mordik E.A. Optimization of methods of diagnostics and assessment of technical condition of highways. *Humanities, social-economic and social sciences*, **2019**, 9, 198-202. DOI: https://doi.org/10.23672/SAE.2019.9.36819
2. Malin P.M. The modern state of road bitumen modification field. *The world of science*, **2021**, 309-311.
3. Vasilchenko E.A., Ryazanova I.S., Sysoev A.R., Soldatov A.A., Yashin S.O. General information about asphalt. *Vestnik nauki i obrazovania*, **2022**, 5 (125), 66-69. ISSN: 2312-8089
4. Gureyev A.A., Chernysheva E.A., Konovalov A.A., Kozhevnikova Yu.V. Proizvodstvo neftyanyh bitumov. *Neft' i gaz*, **2007**, 102 (In Russ.).
5. Gun RB. Neftyanye bitumy. *Nedra*, **1973**, 432 (In Russ.).
6. Kolbanovskaya A.S. Dorozhnye bitumy. *Transport*, **1973**, 264 (In Russ.).
7. Nayler P. Bitumens: Modified. *Encyclopedia of Materials: Science and Technology (Second Edition)*, **2001**, 645-650. DOI: https://doi.org/10.1016/B0-08-043152-6/00123-6
8. Evdokimova N.G., Luneva N.N. The use of additives of different nature for the modification of the properties of bitumen. *Bashkir chemical journal*, **2016**, 4 (23), 49-62.ISSN: 0869-8406
9. Gureyev, A. A. Neftyanye vyazhushchie materialy. *Nedra*, **2018**, 155 (In Russ.). ISBN: 978-5-8365-0484-7
10. Anupam K., Akinmade D., Kasbergen C., Erkens S., Adebiyi F. A state-of-the-art review of Natural bitumen in pavement: Underlining challenges and the way forward. *Journal of Cleaner Production*, **2023**, 382, DOI: https://doi.org/10.1016/j.jclepro.2022.134957
11. Dzhabrailova M.H., Salamova P.H., and Idrisova E.U. Harakteristika, svojstva, poluchenie i primenenie bitumov. *Vestnik Magistratury*, **2021**, 10 (2), 14-15 (In Russ.). ISSN: 2223-4047
12. GOST 22245-90. Viscous petroleum road bitumens. Specifications.**2015**, 9.
13. GOST 11955-82. Road petroleum liquid bitumens. Specifications. **2015**, 9.

14. Paliukaite M., Vorobjovas V., Bulevicius M., Andrejevas V. Evaluation of Different Test Methods for Bitumen Adhesion Properties. *Transportation Research Procedia*, **2016**, 14, 724-731. DOI: https://doi.org/10.1016/j.trpro.2016.05.339

15. Gridchin A.M., Yadykina V.V. Features of interaction of bitumen with mineral materials from sour rocks. *Bulletin of Kharkov National Automobile and Highway University*, **2008**, 40. ISSN: 2219-5548

16. Antunes V., Freire A.C., Quaresma L., Micaelo R. Effect of the chemical composition of fillers in the filler–bitumen interaction. *Construction and Building Materials*, **2016**, 104, 85-91. DOI: https://doi.org/10.1016/j.conbuildmat.2015.12.042

17. Telyashev E.G., Hajrudinov I.R., Kut'in Yu.A., Orazova G.A, Bukanova S.K. Istochniki syr'ya dlya proizvodstva dorozhnyh bitumov v Kazahstane. *Exposition Oil & Gas magazine*, **2008**, 5, 24-26 (In Russ.).

18. Ippolitov E.V., Grudnikov I.B. Asphalt production technology. Recent history and old problems. *Chemistry and Technology of Fuels and Oils*, **2000**, 4 (36), 235-244. DOI: https://doi.org/10.1007/BF02742835

19. Lazzat B., Shaimardan M. Petroleum industry and analysis of producing petroleum products.*International scientific and practical conference world science*, **2016**, 5 (9), 52-54. ISSN: 2413-1032

20. Zholdybaev N.T. Development of integration processes in the petroleum industry of Kazakhstan.*Oil Industry*, **2003**, 7, 40-41. ISSN: 0028-2448

21. Galdina V.D. Modificirovannyebitumy: study guide. *Siberian State Automobile and Highway University in Omsk*, **2009**, 228 (In Russ.).

22. Tyukanko, V., Demyanenko, A., Dyuryagina, A., Ostrovnoy, K., Aubakirova, G. Optimizing the Composition of Silicone Enamel to Ensure Maximum Aggregative Stability of Its Suspensions Using Surfactant Obtained from Oil Refining Waste. *Polymers*, **2022**, 14, 3819. DOI: https://doi.org/10.3390/polym14183819

23. Tyukanko V., Demyanenko A., Dyuryagina A., Ostrovnoy K., Lezhneva M. Optimization of the Composition of Silicone Enamel by the Taguchi Method Using Surfactants Obtained from Oil Refining Waste. *Polymers*, **2021**, 13, 3619. DOI: https://doi.org/10.3390/polym13213619

24. Gohman L.M. Kompleksnye organicheskiye vyazhushchie materialy na osnove bloksopolimerov tipa SBS. Study guide. *Ekon-Inform*, **2004**, 585 (In Russ.).

25. Vdovin E.A, Bulanov P.E., Zhuravlev I.V. The effect of cellulose stabilizing additives on the physical and mechanical characteristics of bitumen. *News of the Kazan State University of Architecture and Engineering*, **2022**, 3 (61), 103-109. DOI: https://doi.org/10.52409/20731523_2022_3_103

26. Galimullin I.N., BashkirtsevaN.Yu.Assessment of the impact of stabilizing additives on the technical properties of road bitumen. *Oil refining and petrochemistry: Scientific and technical achievements and the best practices*, **2015**, 7, 40-44. ISSN: 0233-5727

27. Smirnov D.S., Yagund E.M., Brodneva V.E. Assessment of the impact of cellulose impurities on the properties of crushed stone mastic asphalt concrete. *Kazan State University of Architecture and Engineering*, **2020**, 4 (54), 80-87. ISSN: 2073-1523

28. Mukhametkhanov A.M., Nugmanov O.K., Lebedev N.A. Investigation of technical characteristics of paving bitumen combined with cellulose-containing stabilizing additives. *Kazan State University of Architecture and Engineering*, **2011**, 4 (18), 260-267. ISSN: 2073-1523

29. Yastremsky D.A., Abaydullina T.N., Kudyakov A.I. Crushed-stone and mastic asphalt with cellulose containing additive. Vestnik Tomskogo gosudarstvennogo arkhitekturno-stroitelnogo universiteta, **2019**, 5 (21), 180-191. DOI: https://doi.org/10.31675/1607-1859-2019-21-5-180-191

30. Galdina V.D. Serobitumnye vyazhushchie: monograph. *Siberian State Automobile and Highway University in Omsk*, **2011**, 124 (In Russ.).

31. Ivan'ski M., Ur'ev N.B. Asfal'tobeton kak kompozicionnyj material. *Tekhpoligrafcentr*, **2007**, 668 (In Russ.).

32. Le Huu T. Physical and mechanical properties of sulfur-bitumen binders and sulfur-asphalt concrete. *Engineering Journal of Don*, **2022**,No. 6 (90), 646-664.

33. Vasil'ev Yu.E., Andronov S.Yu., Timokhin D.K., Repin A.M., Repina O.V., Talalai V.V. Sulfur-containing composite materials for transport construction. *Naukovedenie*, **2016**, 3 (34), 112.

34. Turaev F., Beknazarov H., Djalilov A.Study of the modification of the road bitumen element sulfur. *Universum: technical sciences*, **2019**, 2 (59), 65-69.

35. Pen V.R., Levchenko S.I. Performance properties and durability modified rubber-bitumen composites. *Actual problems of aviation and aerospace systems*, **2019**, 388-390.

36. Beliaev P.S., Malikov O.G., Merkulov S.A., Frolov V.A. Solution to the problem waste rubber products by modifying the road binders. *Proceedings of the Voronezh state university of engineering technologies*, **2014**, 2 (60), 129-131. ISSN: 2226-910

37. Ivanov S.A., Shabayev S.N., Tyuryukhanov K.Yu. Recycling crumb rubber by production modified bitumen. *Engineering Journal of Don*, **2022**, 9 (93), 143-160.

38. Belyayev P.S., Zabavnikov M.V., Malikov O.G., Volkov D.S. Issledovanie vliyaniya rezinovoj kroshki na fiziko-mekhanicheskie pokazateli neftyanogo bituma v processe ego modifikacii. *Vestnik Tambovskogo gosudarstvennogo tekhnicheskogo universiteta*, **2005**, 4 (11), 923-930 (In Russ.).ISSN: 0136-5835

39. Dolinskaya R.M., Prokopchuk N.R. Influence of rubber crush on the properties of oil bitumen. *Proceedings of BSTU: Series 2. Chemical Engineering, Biotechnologies, Geoecology*, **2021**, 1 (241), 172-175. ISSN: 2520-2669

40. Vorobeva A.A., Emelyanycheva E.A., Abdullin A.I. The influence of crumbed rubber on petroleum bitumen properties. *Bulletin of the technological university*, **2018**, 10 (21), 59-62. ISSN: 1998-7072

41. Rozental' D.A., Tabolina L.S., Fedosova V.A.Modifikaciya svojstv bitumov polimernymi dobavkami. *CNIIT Eneftekhim*, **1988**, 49 (In Russ.).

42. Rozental' D.A., Bereznikov A.V., Kudryavcev I.N. Bitumy. Poluchenie i sposoby modifikacii: study guide. *LTI*, **1979**, 80 (In Russ.).

43. Mamadiev N.A. Polimery i polimernye nanokompozity dlya proizvodstva bitumnyh vyazhushchih. *Vestnik magistratury*, **2021**, 5 (116), 26-29 (In Russ.).ISSN: 2223-4047

44. Shiryaev A.O., Obuhov A.G., Vysockaya M.A., ShekhovcovaS.Yu. Polimernye modifikatory bitumnyh vyazhushchih. *Vestnik Belgorodskogo gosudarstvennogo tekhnologicheskogo universiteta im. V. G. SHuhova*, **2017**, 11, 48-54 (In Russ.). ISSN: 2071-7318

45. Polacco G., Berlincioni S., Biondi D., Stastna J., Zanzotto L. Asphalt modification with different polyethylene-based polymers. *EurPolym*, **2005**, 12 (41), 31-44. DOI: https://doi.org/10.1016/j.eurpolymj.2005.05.034

46. Dyuryagina A.N., Lutsenko A.A., Tyukanko V.Yu.Study of the disperse effect of polymeric surface-active substances in acrylic dispersions used for painting oil well armature. Bulletin of the Tomsk Polytechnic University Geo Assets Engineering, **2019,** 8 (330), 37-44. DOI: https://doi.org/10.18799/24131830/2019/8/2210

47. Attaelmanan M., Cheng PF., AI AH. Laboratory evaluation of HMA with high density polyethylene as a modifier. *Constr Build Mater*, **2011**, No. 5 (25), 64-70. DOI: https://doi.org/10.1016/j.conbuildmat.2010.12.037

48. Stastna J., Zanzotto L., Vacin OJ. Viscosity function in polymermodified asphalts. *Colloid Interface Sci*, **2003**, No. 259, 2-7. DOI: https://doi.org/10.1016/s0021-9797(02)00197-2

49. Dyuryagina A.N., Ostrovnoj K.A., Golodova I.V., SHajmerdenova Z.N., Kozik D.Yu., Dyusikeeva A.K.Optimizaciya processov vodopodgotovki oborotnoj vody zavoda po vtorichnoj pererabotke plastmass. *Bulletin of the Tomsk Polytechnic University, Geo Assets Engineering*, **2021**, 9 (332), 187-195. DOI: 10.18799/24131830/2021/9/3368

50. Lewandowski L.H. Polymer modification of paving asphalt binders. *Rubber Chemistry and Technology*, **1994**, 3 (67), 447-480. DOI: https://doi.org/10.5254/1.3538685

51. Kotenko N.P., Shcherba Yu.S., Evforitsky A.S. Effect of polymer and functional additives on the properties of bitumen and asphalt-concrete. *Bulletin of Higher Educational Institutions. North Caucasian Region. Technical Sciences*, **2019**, 1 (201), 94-99. DOI: https://doi.org/10.17213/0321-2653-2019-1-94-99

52. Vasilovskaya G., Druzhinkin S., Peresypkin E., Berseneva M.The development of polymer-bitumen binder compositions for preparation of polymer-modified asphalt cements. *Engineering Journal of Don*, **2023**, 3 (99), 399-408

53. Chen J.S., Liao M.C., Lin C.H. Determination of polymer content in modified bitumen. *Materials and structures*, **2003**, 9 (36), 594-598. DOI: https://doi.org/10.1007/bf02483278

54. Biglova R.Z., Nasretdinova R.N. Evaluation of adhesion and cohesion properties of road bitumens modified by butadientistic rubber. *Reports of the Bashkir University*, **2018**, 3 (23), 734-738.ISSN: 1998-4812

55. Zhu J., Birgisson B., Kringos N. Polymer modification of bitumen: advances and challenges. *European polymer journal*, **2014**, 1 (54), 18-38. DOI: https://doi.org/10.1016/j.eurpolymj.2014.02.005

56. Minhairova A. I., Zakirova L. Yu., Vol'fson I. S., Ayupov D. A., Murafa A. V., Hozin V. G., Hakimullin Yu. N. Modifikaciya dorozhnyh bitumov smesevymi termo elastoplastami. *Herald of technological university*, **2012**, 17 (15), 120-122 (In Russ.).

57. Belova N.A., Israilova Z.S., Strakhova N.A. Problems and perspektivy production oil bitumen. *Herald of Daghestan State Technical University. Technical Sciences*, **2016**, 2 (41), 139-149. ISSN: 2073-6185

58. Platonov, A.P. Primenenie aktivnyh dobavok pri proizvodstve okislennyh bitumov. *Avtomobil'nyedorogi*, **1992**, 4, 10-12 (In Russ.).

59. Bembel', V.M. Modifikaciya neftyanyh bitumov. *Tezisy dokladov Mezhdunarodnoj konferencii po himiinefti*, **1991**, 307 (In Russ.).

60. Bolatbaev K.N., Dyuryagina A.N., Ostrovnoj K.A. Modificirovanie kompozitov poverhnostno-aktivnymi veshchestvami. *North Kazakhstan University named after M. Kozybayev*, **2005**, 186p. (In Russ.).

61. Dyuryagina A.N. Colloid chemistry: study guide. *ESPI Almaty*, **2022**, 220 p.(In Russ.).

62. Shalamanov V.A., Zaharova P.M., Moiseev D.N. Study of the influence of adhesive additives "Amdor-10" and "Polyram l-200" on physical and mechanical characteristics of the bitumen.*Vestnik Kuzbasskogo gosudarstvennogo tehničeskogouniversiteta*, **2017**, 2 (120), 166-170.ISSN: 1999-4125

63. Pyrig YA.I. Obzor metodov ocenki scepleniy abitumov s kamennymi materialami. *Bulletin of Kharkov National Automobile and Highway University*, **2019**, 85, 73-82 (In Russ.). DOI: https://doi.org/10.30977/BUL.2219-5548.2019.85.0.73

64. Dyuryagina A., Lutsenko A., Ostrovnoy K., Tyukanko V., Demyanenko A., Akanova M. Exploration of the Adsorption Reduction of the Pigment Aggregates Strength under the Effect of Surfactants in Water-Dispersion Paints. *Polymers*, **2022**, 14, 996. DOI: https://doi.org/10.3390/polym14050996

65. Dyuryagina A., Lutsenko A., Demyanenko A., Tyukanko V., Ostrovnoy K., Yanevich A. Modeling the wetting of titanium dioxide and steel substrate in water-borne paint and varnish materials in the presence of surfactants. *Eastern-European Journal of Enterprise Technologies*, **2022**, 1(6(1150), 31-42. DOI: https://doi.org/10.15587/1729-4061.2022.252757

66. Ostrovnoy K., Dyuryagina A., Demyanenko A., Tyukanko V. Optimization of titanium dioxide wetting in alkyd paint and varnish materials in the presence of surfactants. *Eastern-European Journal of Enterprise Technologies*, **2021**, 4(6(112), 41-50. DOI: https://doi.org/10.15587/1729-4061.2021.237879

67. Tyukan'ko V.YU., Dyuryagina A.N., Ostrovnoj K.A., Dem'yanenko A.V. Study of wetting of aluminum and steel substrates with polyorganosiloxanes in the presence of nitrogen-containing surfactants. *Bulletin of the Tomsk Polytechnic University, Geo Assets Engineering*, **2017**, No. 11 (328), 75-82.ISSN: 2500-1019

68. Ramaswamy S., Low E. The effects of Amino antistrip additives on stripping of bituminous mixes. *Highways and Transportation*, **1990**, 5 (37), 9-13.

69. Nazimuddin M., Wasiuddin C., Fogle M., Musharraf M., Edgar A. Effect of antistrip additives on surface free energy characteristics of asphalt binders for moisture-induced damage potential. *Journal of Testing and Evaluation*, **2007**, 1 (35)

70. Dyuryagina A.N., Ostrovnoy K.A., Kozik D.Yu.Modifying effect of petrochemical waste processing products on wetting and stabilization of solid-phase particles. Bulletin of the Tomsk Polytechnic University, Geo Assets Engineering, **2021**, 12 (322), 164-172. DOI: https://doi.org/10.18799/24131830/2021/12/3124

71. Dyuryagina A.N., Byzova Yu.S., Ostrovnoy K.A., Tyukanko V.Y. Utilization of the waste sealing liquid component in asphalt concrete pavements. *Bulletin of the Tomsk Polytechnic University, Geo Assets Engineering*, 8 (322), **2021**, 80-86. DOI 10.18799/24131830/2021/04/3150

72. Kandhal P. S. Field and Laboratory Investigation of Stripping in Asphalt Pavements: State of the Art Report. *Transportation Research Board*, **1994**. 1454, 36-47.

73. Liu Y., Apeagyei A., Ahmad N., Grenfell J., Airey G. Examination of moisture sensitivity of aggregate-bitumen bonding strength using loose asphalt mixture and physico-chemical surface energy property tests. *International Journal of Pavement Engineering*, **2014**, 7 (15), 657-670.

74. ASTM D 3625-2012 Standard Practice for Effect of Water on Bituminous-Coated Aggregate Using Boiling Water. *ASTM International*, **2012**, 2.

75. Kennedy T. W., Roberts F. L., Anagnos J. N. Texas boiling test for evaluating moisture susceptibility of asphalt mixtures. *Texas State Department of Highways and Public Transportation*, **1984**, 5 (253), 36.

76. Vasil'ev V.V., Ivkin A.S., Salamatova E.V., MaidanovaN.Ya.V. Improvement of methods for determining bitumen cohesion with mineral materials. *Bulletin of StPb SIT (TU)*, **2018**,. 42 (68), 58-61.

77. Kolbanovskaya A.S. Metod krasitelej dlya opredeleniya scepleniya bituma s mineral'nymi materialami. *Avtotransizdat*, **1959**, 32 (In Russ.).

78. Kortyanovich K.V., Evdokimova N.G., Zhirnov B.S. Dielektricheskaya pronicaemost' kak pokazatel' harakterizuyushchij adgezionnye svojstva bitumov. *Neftegazovoedelo*, **2016**, 2, 35(In Russ.).

79. Abdullin A.I., Emel'yanycheva E.A, Diyarov I.N. Ocenka adgezii bituma k mineral'nomu materialu v asfal'tobetone na osnove ego smachivayushchihsvojstv. *Bulletin of the Technological University*, **2009**, 4, 257-259 (In Russ.).

80. Xie J., Wu S., Pang L., Lin J., Zhu Z. Influence of surface treated fly ash with coupling agent on asphalt mixture moisture damage. *Constr. Build. Mater*., **2012**, 30, 340-346.DOI: https://doi.org/10.1016/j.conbuildmat.2011.11.022

81. Gronniger J., Wistuba M.P., Renken P. Adhesion in Bitumen-Aggregate-Systems. *Road Mater. Pavement Des*., **2010,** 11(4), 881-898. DOI: https://doi.org/10.1080/14680629.2010.9690311

82. Byzova Yu.S., Dyuryagina A.N., Ostrovnoi K.A., Gorshkova T.A., Savelyeva P.O. Investigation of the wetting effect of surfactants of various nature in the bitumen composition. *Chemical Journal of Kazakhstan*, **2023**, 1 (81), 44-53. DOI: https://doi.org/10.51580/2023-1.2710-1185.05

83. Kosarev I.V., Ignatova T.A., Ivanchenko A.E. Penetraciya neftyanogo bituma. *Teoriya i praktika sovremennoj nauki*, **2017**, 1 (19), 574-576(In Russ.).

84. Shorin V.A., Velsovsky A.Y., Myasnikova S.A. Study of penetration (viscosity) of petroleum road bitumen from various manufacturers. *Bulletin of Vologda State University*, **2022**, 4 (18), 31-33. ISSN: 2658-3399

85. Kolmakov G.A., Zanozina V.F., Karataev E.N., Ivanov P.S., Grishin D.F., Zorin A.D. Effect of sulfur-containing acids on the penetration and softening point of asphalts obtained from acid sludge. *Petroleum Chemistry*, **2007**, 2 (47), 139-142.ISSN: 0028-2421

86. Galkin A., Pyrih Ya. Conditions of measurement of bitumen binders cohesion strength. *Bulletin of Kharkov National Automobile and Highway University*, **2013**, 1 (99), 71-77. ISSN: 2219-5548

87. Galkin A., Pyrih Ya.Conditions of measurement of bitumen binders cohesion strength. *Bulletin of Kharkov National Automobile and Highway University*, **2017**, 79, 47-51. ISSN: 2219-5548

88. Bitumen and bituminous binders. Determination of cohesion of bituminous binders with pendulum test: EN 13588-2008 - Brussels. *European committee for standardization*, **2008**, 22.

89. Isaac L. Howard, Walter S. Jordan, Jason M. Barham, Alejandro Alvarado, Ben C. Cox. Performance Oriented Guidance for Mississippi Chip Seals, Volume I. *Mississippi State University*, **2013**, 191.

90. Hagos E.T. The Effect of Aging on Binder Properties of Porous Asphalt Concrete. *Wohrmann Print Service*, **2008**, 321.

91. VasilievYu., Subbotin I., ShelestS., StepanishevA.Bitumen cohesion and adhesion strength quantitative assessment method and system research. *Naukovedenie*, **2014**, 5 (24), 26.

92. Babkov E.I. Kogeziometr sdvigovyj [The invention relates to the field of control of the physical properties of binders, mainly bitumen]. *Patent SU, No. 305388*, **1971**.

93. Babcock, Gregg B. Study of Asphalt Binders using Lap Shear Bonds. *Proceedings of the 43rd Annual Conference of Canadian Technical Asphalt Association*, **1998**, 43, 1-15. ISSN: 0712-2470

94. The Vialit device designed to analyze the adhesion of road bitumen: https://rm-pro.ru/catalog/oborudovanie-dlya-ispytaniy-dorozhno-stroitelnykh-materialov-superpave/pribor-crt-vcp-kogeziya/

95. Dzhilavdari I. Z., Mekid S., Riznookaya N. N. Ustrojstvo i metodika izmereniya momentov sil soprotivleniya kacheniyu na pyatne kontakta. *Pribory i metody izmerenij*, **2019**, 4 (10), 308-321 (In Russ.). DOI: https://doi.org/10.21122/2220-9506-2019-10-4-308-321

96. Malyar V. V., Psyurnik V. A., Lapchenko A.S. Opredelenie modulya uprugosti asfal'topolimerbetonov dlya rascheta konstrukcij dorozhnyh odezhd. *Bulletin of Kharkov National Automobile and Highway University*, **2008**, 40 (In Russ.).

97. Canestrari, F., Cardone, F., Graziani, A., Santagata, F., Bahia, H. U. Adhesive and Cohesive Properties of Asphalt-Aggregate Systems Subjected to Moisture Damage. *Road Materials and Pavement Design*, **2010**, 11,11-32. DOI: https://doi.org/10.1080/14680629.2010.9690325

98. Emel'yanycheva E.A., Abdullin A.I. Issledovanie neftyanyh modificirovannyh bitumov metodom atomnoj silovoj mikroskopii. Vestnik Kazanskogo tekhnologicheskogo universiteta, **2012**, 15 (12), 172-174 (In Russ.).

99. Yu X, Burnham NA, Tao M. Surface microstructure of bitumen characterized by atomic force microscopy. *Adv Colloid Interface Sci*, **2015**, 218, 17-33. DOI: https://doi.org/10.1016/j.cis.2015.01.003

100. Zhang H.L., Yu J.Y., Feng Z.G., Xue L.H., Wu S.P.. Effect of aging on the morphology of bitumen by atomic force microscopy. *J Microsc*, **2012**, 246, 11-9. DOI: https://doi.org/10.1111/j.1365-2818.2011.03578.x.

101. Loeber L, Alexandre S, Muller G, Triquigneaux J, Jolivet Y, Malot M. Bituminous emulsions and their characterization by atomic force microscopy. *J Microsc*, **2000**, 198, 106. DOI: https://doi.org/10.1046/j.1365-2818.2000.00667.x.