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A REVIEW OF ROAD BITUMEN MODIFICATION METHODS. PART 1 – PHYSICAL MODIFICATION

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Abstract. The information in this study is based on a thorough review of recent articles related to the production of binders for road construction and the improvement of their performance properties. The main attention is paid to the physical modification of road bitumen with polymer modifiers. The influence of the three main types of polymers (thermoplastics, elastomers, and thermoplastic elastomers) on the main physical and mechanical properties of bitumen-polymer compositions is shown. The main technological parameters and features of the physical modification of bitumen by different types of polymer modifiers have been determined.

Keywords: bitumen; physical modification; thermoplastics; elastomers; thermoplastic elastomers.

1. Introduction

Road bitumen is one of the main components used in road construction and repair. The world production of road bitumen depends on many factors, such as the demand for construction materials, the state of road infrastructure, and the level of economic development of different countries[1–4].

Unfortunately, modern petroleum bitumen cannot fully meet all the requirements for the transport and operational characteristics of asphalt concrete. This is mainly due to the increase in the number of large cars on the roads and increased speed. To improve the operational properties of bitumen, various additives are added to it, and some of them have been successfully used in various industries. Modifiers and additives that were used to improve the performance of bitumen include polymers, chemical modifiers, fillers, oxidizers, antioxidants, and others[5–10].

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Temperature and weather-climatic factors are the main factors that affect the aging of bitumen, due to which it becomes brittle and loses its binding properties. As a result, cracks are formed on the road surface. Various polymer additives are used to avoid this negative phenomenon and extend the service life of coatings[11–12].

The main disadvantages of using distilled and oxidized bitumen are their low heat resistance and poor adhesion with traditional acidic mineral fillers, which, accordingly, causes the formation of ruts and cracking of asphalt concrete coatings using such binder materials, which in turn reduces the service life of such coatings. To solve these problems, distillation and oxidized bitumen is modified with polymers. As a rule, these are plastics processing waste (PE, PP, PET, and others) and block-copolymers of the styrene-butadiene-styrene (SBS) type specially synthesized for this purpose.

Usually, for the production of bitumen, the oil processing residues are used, namely residues after such processes as vacuum distillation of oil (tars), thermal (heavy coking gas oils), thermocatalytic (heavy gas oils of catcracking and hydrocracking), deasphalting (asphalts), and extraction purification (extracts)[13].

The method of deep vacuum distillation of oil residues is quite common in the production of road bitumen. In many countries where there is a need for high-quality road bitumen, the deep vacuum distillation method is one of the main production methods (for example, in the USA). Oil residues from secondary processes and extracts of selective purification of oil fractions are usually mixed and sent for deep vacuum distillation to remove light fractions. The share of such raw materials in the production of bituminous materials is small. Rectification is carried out under vacuum (10–100 mm Hg) at 623–698 K, which is equivalent to a temperature of more than 808 K at atmospheric pressure[13,14].

The properties of vacuum oil residue can be changed (modified) using solvent deasphalting processes, such as the ROSE (Residuum Oil Supercritical Extraction) process. As a rule, low molecular weight alkanes are used as solvents in this case – propane, butane, isobutane, pentane, and others. The obtained bitumen is characterized by a high content of asphaltenes, which leads to high stiffness. Such bitumen is blended with traditional distillation bitumen to give it higher stiffness as well (lower P298 and higher SP)[15–17].

Processes of oxidation of oil residues with oxygen in air to obtain binders for road construction have become widely used. There are two main processes of tars oxidation for bitumen production[13,14,18,19].

1) light oxidation – rectification with air blowing (air-rectification, air-rectified bitumen);

2) hard oxidation – oxidation of bitumen in the reactor (bitumen oxidation, oxidized bitumen).

Oxidation of oil residues reduces P298 and increases SP, which leads to an increase in the penetration index (IP800; according to EN 13924-1). Therefore, IP800 is considered to be a good indicator of the oxidation degree. The recommended criteria for differentiating oxidized bitumen[19] are:

– air-rectified bitumen – IP800 ≤ 2;

– oxidized bitumen – IP800 > 2.

The mechanism is mainly based on the oxidation of light compounds of oil residues, which, in turn, increases polarity of molecules[20]. An increase in polarity increases the polydispersity[21] of the interaction between molecules, resulting in an increase in bitumen stiffness. Since the autonomous process of blowing oil residues with air mainly depends on the loss of volatile substances and the increase in polarity of molecules, it requires a lot of time, and energy and leads to the formation of secondary organic aerosols. To solve this problem, catalysts of the oxidation process were used. The use of acids for this purpose began in 1939 when Lewis acids (such as boron fluoride and ferric chloride) and Brønsted acids (sulfuric acid) were used as catalysts in the bitumen air-blowing process. The use of polyphosphoric acid ($H_{n+2}P_nO_{3n+1}$; M = 337.93) and active nanoparticles is also mentioned.

A well-known process of easy oxidation of oil residues is BITUROX®[15,18,22]. Today, this is one of the most modern methods of obtaining binder materials from distillation products, which is carried out in continuous reactors[18]. The continuity of the process ensures product homogeneity, i. e. homogeneity of the properties of the entire structure of the final product.

Air-rectified bitumen is recommended for modification with polymers[13,15,23].

The technology for the production of oxidized bitumen is carried out in batch reactors and consists of oil residues oxidation with air oxygen at 477–533 K, with an air consumption from 2 to 6 $m^3/(m^2 \cdot min)$, lasting up to 12 h. The batch oxidation reactor is less complex from a technological point of view than the BITUROX® reactor. In the process, reactions of dehydrogenation, dealkylation, oxidative polymerization, polycondensation, and cracking with subsequent compaction of its products take place. The main part of air oxygen is involved in the formation of water and carbon dioxide, and a small part is involved in the formation of organic substances containing oxygen[13,18,24].

Distillation and oxidized bitumen make up more than 99 % of the materials used for road pavement and roofing[25]. Alternative binder materials for road construction are also known, namely biobitumen[26], lignin[27], shale, bituminous sands, biomass, microalgae, and natural bitumen[28]. Natural bitumen can be considered an environmentally friendly alternative to traditional bitumen, as it is a mixture of bitumen and minerals that are naturally occurring and abundant[29].

Bitumen obtained in various processes (distillation, oxidation, and deasphalting) are mixed to obtain grades with the necessary properties. Such bitumen is called compounded bitumen.

Both for road surfaces and for industrial applications, bitumen must be resistant to climatic conditions and traffic loads. For this reason, rheological properties play a key role[30]. From a functional point of view, bitumen must be sufficiently fluid at high temperatures (≈433 K) to be pumped and used to create a uniform coating with mineral materials after mixing. At the same time, bitumen must be hard enough at high temperatures to prevent rutting (corresponding to local temperatures, ≈ 333 K) but remain soft and elastic at low temperatures to prevent cracking. All these requirements are difficult to fulfill for most available "pure" bitumen (distillation and oxidized). In addition, in some applications, conventional "pure" bitumen may not be satisfactory in terms of the required performance properties, as it becomes brittle when cooled and softens when heated. The limited operating temperature range is the main disadvantage of "pure" bitumen, which limits its use for both roofing and road construction. In addition, due to the sharp increase in traffic speeds and loads, unplanned overloads have significantly reduced the service life of bituminous pavements, increasing maintenance costs and risks for users. Therefore, to improve the operational properties of "pure" bitumen today, various additives are used. Modifiers and additives that have been used to improve the quality of bitumen include polymers, chemical modifiers, fillers, oxidants and antioxidants, hydrocarbons, and anti-flaking additives. In general, these modifiers can be divided into two groups: physical and chemical. The following chapters are devoted to a discussion of the chemical composition of bitumen to describe the main properties and, mainly, to provide further coverage of science and technology of bitumen modification[30].

2. Physical Modification

Two empirical indicators were selected as the main markers of physical modification processes, namely SP, which characterizes heat resistance, and E298 – elastic recovery. The necessary values of these two indicators ensure resistance to the formation of ruts on roads. An increase in SP leads to a decrease in P298, *i. e.*, the modification leads to a change in the grade of bituminous material according to the penetration classification (lowering of the grade). Therefore, it is better to use higher grades of bitumen, 70/100 and 100/150 for modification, to prevent the use of plasticizers, what is especially important for thermoplastic modifiers. This type of modifier does not chemically interact with the constituent parts of bitumen, the increase in SP and E298 occurs only as a result of the physical mixing process. Physical modification is also called mechanical one. According to the principle of action, physical modifiers are divided into groups:

– thermoplastics (increase SP);
– elastoplasts (increase E298);
– thermoelastoplasts (increase SP and E298)[31–33].

To obtain PMB with the necessary heat resistance and elastic recovery, bitumen should be modified with thermoplastic elastomers, or in combination with thermoplastics and elastomers (separately or in the form of a complex polymer). Let's consider each of these groups of modifiers in more detail[34–39].

2.1. Physical Modification of Bitumen by Thermoplastics

Thermoplastics as bitumen modifiers are not produced directly, as their large amount accumulates after initial use, therefore, as a rule, recycled plastic waste is used to modify bituminous materials. In the European Union, the majority of plastic waste (41 %) is incinerated and approximately 30 % of plastic waste is recycled[40]. According to the US Environmental Protection Agency (EPA), in 2017, 35,370 tons of plastic were produced in the US, only 8.4 % of which (2,960 tons) was recycled, and the rest – 26,820 tons (75.8 %) was buried in landfills[41]. Plastic waste threatens the environment and human health[42], so it is advisable to reuse it, for example, as bitumen modifiers. This ensures the disposal of these wastes and improves the operational characteristics of bitumen, especially at higher operating temperatures of coating[43–47].

Thermoplastics as physical modifiers include the following polymers: different types of polyethylene – PE, namely high density – HDPE, medium density – MDPE, low density – LDPE, and linear low density – LLDPE[48–50]; polypropylene – PP[51–52]; polyvinyl chloride – PVC[53]; polyethylene terephthalate – PET[54]; polystyrene – PS[55]; ethylene-vinyl acetate – EVA[56]; acrylonitrile-butadiene-styrene – ABS[57]; polyurethane – PU[58]. HDPE and LDPE are the most common of all types of polyethylene[49].

In particular, most of single-use plastic products such as bottles, packaging, and single-use products are made of LDPE, HDPE, and PS, while long-term plastic products are made of PET, PP, PVC, EVA, and others[47].

Table 1 shows melting points and the main sources of plastic waste.

There are two main approaches used to add waste plastics to ACM: wet and dry processes[60]. In the wet process, plastic waste is added directly to bitumen at high temperatures, where mechanical mixing is required to obtain a homogeneous plastic-modified mixture. Mixing temperature and mixing time depend on the nature of the plastic waste source and the binder. In the dry process, plastic waste is added directly to ACM, either as a partial filler replacement or as a blend modifier. When the addition of plastic waste is done by the wet method, the plastic waste is added to bitumen to change its properties before it comes into contact with the aggregates[61]. When plastics are added using the dry process, the waste plastics are mixed with mineral fillers to effectively act as reinforcing materials[60].

Table 1. Melting point and main sources of waste generation

Type	Melting point, K	Sources[41]
LDPE	381–393[46,56,59]	Packages for various purposes
HDPE	402–422[46,56,59]	Containers for detergents, shampoos, motor oils
PP	418–438[51]	Lids for containers, containers for medicines, packaging tape
PVC	433–483[41,53]	Plumbing pipes and fittings, wire insulation
PET	533[41]	Disposable bottles for drinks
PS	483–522[41]	Disposable dishes, trays and containers for food storage
EVA	338–353[41]	Soles for shoes, thin films and wire insulation
ABS	there is no exact melting point[41]	Electronic plastic, for example, for the manufacture of laptops, televisions, telephones and others
PU	there is no exact melting point[41]	Upholstered furniture and mattresses, shoes, cars, medical equipment, as well as thermal insulation of buildings

Table 2. Optimal technological parameters of modification of thermoplastics with recycled waste

Type	Optimum content in bitumen, wt%	Modification temperature, K	Modification time, min	Mixing speed, rev/min	Literature source
PE	3–6	418–463	60–150	1750–4000	[48]
PP	3–6	433–453	45–90	1800–4000	[51]
PVC	4–8	433–453	60–180	1300–2000	[53]
PET	2–8	453	60	13000	[56]
EVA	3–5	413–453	80–120	1800–3000	[56]
PS	4–6	423–463	90–120	3000	[55]

Plastic waste for modification of bituminous materials is used in the form of granules or crushed material, i. e., before modification, this waste must be prepared[41,47,62].

The optimal technological parameters of mixing, which are used to modify bitumen with various thermoplastic wastes, are given in Table 2.

The obtained PMB in the modification process must be homogeneous, so the mixing temperature of bitumen with thermopolymers must be higher than the melting point[49,62]. Also, one of the most important properties of thermopolymers is density, which affects dosage and compatibility with bitumen. The density of bitumen ranges from 0.85 to 1.05 g/cm^3. The densities of HDPE, LDPE, PP, EVA are in the range of 0.85–1.05 g/cm^3, while PET, PS, PVC, ABS and PU have a higher density than bitumen[41,47]. Summarizing the data in Table 2 for these seven types of thermoplastics, the mixing temperature is between 423 and 453 K, the mixing time is between 1 and 3 hours, and the mixing speed is between 1200 and 5000 rpm.

Table 3 summarizes the impact of adding thermoplastics to bitumen.

worsens the low-temperature behavior of the binder (LTBB), which is a significant disadvantage of this type of modifiers. LDPE, PP, EVA, ABS, and PU waste have good compatibility with bitumen compared to other types of plastic waste, i.e. homogeneous PMB can be obtained. It is more appropriate to add poorly soluble thermopolymers (HDPE, PVC, PET, and PS) directly to ACM[41,47,62].

Among thermoplastics, petroleum polymer resins, which are the by-products of thermodestructive processing of combustible fossils, can be used to improve the properties of bitumen, namely: increasing heat resistance and adhesion to mineral materials[65,66].

The effectiveness of using indene-coumarone resin as a polymer modifier has also been proven[67,68]. It is a polymerization product of the compounds (mainly indene, coumarone, and styrene) contained in the volatile products of the coking process of black coal (for example, “heavy” benzene). The addition of thermoplastic indene-coumarone resin to bitumen allows to increase SP (from 320 to 325 K) and adhesion to the surface of acidic mineral fillers. On the other hand, the plastic properties of bitumen deteriorate (P298 and D298 decrease).

Table 3. Properties of PMB using thermoplastics

Type	Properties of PMB using thermoplastics				Literature source
	Homogeneity	Heat resistance	Flexibility at low temperatures	Viscosity	
LDPE	(+)	(+)	–	(+)	[50]
HDPE		(+)	–		[48]
PP	(+)	(+)	–	(+)	[51, 52]
PVC	–	(+)	–	(+)	[53]
PET	–	(+)	–	(+)	[63]
PS	–	(+)	–	(+)	[55]
EVA	(+)	(+)	(+)	(+)	[56]
ABS	(+)	(+)	–	–	[64]
PU	(+)	–	–	(+)	[57, 58]

Table 3 shows that the addition of plastic waste increases the heat resistance and viscosity of bitumen, and

The use of thermoplastic waste as an independent bitumen modifier is rarely found in practice. The reason is that it is impossible to improve the key properties of bitumen using only one type of plastic waste. Recently, more and more studies have investigated the properties of modified binders containing plastic waste and various materials[62,69].

The combination of two polymers is carried out by extrusion before adding them to bitumen or by adding individual polymers in a defined proportion[62]. Most research is related to the combination of elastomers and thermoplastics, such as tire rubber and PE[70], tire rubber and EVA[71], tire rubber and PP[72], tire rubber, elastomer and PE[73–74]. In complex modification, PE helps to increase SP, while rubber improves low-temperature properties. Nasr and Pakshir[75] tested three combinations of PET waste and rubber crumb blends. Scientists[76] suggested that modification with an LDPE/HDPE blend in combination with conventional thermoplastic elastomer (SBS) could produce an elastic binder more resistant to deformation than using the same amount of SBS alone. Other studies have shown that plastic waste can be mixed with some common materials such as sulfur and polyphosphoric acid to modify bitumen[62].

There is no doubt that thermopolymers are quite effective in improving the high-temperature performance of coatings but there are still limitations to the use of these modifiers due to the heterogeneity of such PMBs and poor low-temperature properties. Composite pre-treatment and modification techniques can improve the disadvantages of PMB using thermoplastics.

2.2. Physical Modification of Bitumen with Elastomers

This group of modifiers includes natural (NR) and synthetic rubber[30].

NR is extracted from trees and used as a biopolymer for bitumen modification. NR as a biopolymer has been effectively used for many decades in the production of automobile tires, as well as in construction, including road construction[77, 78].

Liquid (NRL, latex) and coagulated (CLNR, solid) NR are used to modify bitumen[79,80]. The production of NR is simple and does not require a complex process to produce products for modification[81,82].

According to Saowapark[80], when adding NRL to bitumen in the amount of 0.6–4.5 wt. % (423 K, 30 min, 500 rpm), there is a slight decrease in P298 (from 67 to 64–57 dmm) and an increase in SP (from 319 to 331 K). A similar study was conducted by Shaffie[83], who modified bitumen with NRL in the amount of 4–12 wt. % (433 °C, 60 min, 1270 rpm). P298 decreased from 92 to 49.8–55.5 dmm, and SP increased from 317 to 326.4–330.4 K. The high hardness of bitumen can be associated with NRL macromolecules. The chains diverge in bitumen, distributing the softening load and holding the bitumen molecules together. Thus, an increase in the content of NRL macromolecules leads to resistance to softening and an increase in the bearing capacity of bitumen.

Other studies have shown that at high speed (> 4000 rpm) and temperature (423–433 K) the time of NRL bitumen dispersion was reduced to 30–40 min[84]. It should be noted that an increase in the mixing speed reduces the time required to achieve the same dispersion.

Wen *et al.*[85] concluded that NRL increases the low-temperature resilience of the resulting PMB, which also increases the low-temperature flexibility of bitumen.

Despite its advantages, NRL has also a disadvantage, as it contains 55–60 wt. % of water, which directly affects the properties of bitumen and ACM, causing foaming during the mixing process, which is a serious problem[77]. The presence of this amount of water makes it possible to use NRL in the production of BE[86] and foamed bitumen[87].

The chemical properties of CLNR are similar to those of NRL. In addition, CLNR is suitable for mixing with bitumen due to its low water content. Literature on CLNR-modified bitumen is scarce, as it is still in the early stages of research and implementation. Recent studies by Azahar[82] showed the effect of CLNR on PMB properties. CLNR was pretreated with toluene to soften it for mixing with bitumen. P298 decreased by 20 % and SP increased by 8 % when 5 wt. % of CLNR was added to bitumen. The elastic recovery and stiffness of bitumen were attributed to the globular particles and porous surface of CLNR, which can absorb bitumen extremely strongly[77].

Despite the advantages of using NR for bitumen modification, some disadvantages limit its use on a large industrial scale. Natural rubber is a very valuable biomaterial compared to other biopolymers, so NR has been commercially processed into synthetic rubber, mainly because of the huge gap between production and demand. Industrial production of NR was 13 million tons in 2017, and synthetic rubber was 15 million tons[77]. From another point of view, even if several studies have shown certain advantages of NR-modified bitumen for road pavement, there are still some doubts about asphalt concrete characteristics and mechanical properties in the whole range of operating temperatures.

Synthetic rubber is an artificial rubber, which is produced by industrial enterprises via synthesis from petroleum raw materials (1,3-butadiene, isoprene, styrene, etc). It has properties of elastic recovery or deformation under stress, but can also return to its original size without ultimate deformation. Styrene butadiene rubber (SBR), polyisoprene, polybutadiene, polychloroprene, and tire rubber are among the most widely used synthetic rubbers today. SBR and rubber chips are most commonly used to modify bitumen. Rubber crumbs obtained from worn car tires are used for the production of so-called rubberized bitumen binders. To date, many studies on synthetic rubbers have been conducted[88–90].

SBR is recognized as an effective modifier for PMB production. Modification by SBR provides bitumen with better heat resistance, flexibility at low temperatures, increased adhesive strength, and resistance to deformations. However, unfavorable storage stability or compatibility between SBR and bitumen limits the application of SBR for bitumen modification[88].

It is known that the use of waste rubber is effective in improving the rheological properties of bitumen and at the same time solves the environmental problem of recycling car tires[79].

In the wet process, bitumen is heated to 449–499 K in a sealed tank and then crumb rubber is added (typically more than 15 % by weight of the bitumen). The mixture is kept at 423–491 K for 45–60 min to ensure the interaction between rubber and bitumen. The rubber particles swell and increase by 3–5 times their original size due to the absorption of maltenes. This causes an increase in the asphaltene content, resulting in a higher viscosity of bitumen. The rate and degree of swelling strongly depend on the process temperature, and the rate increases with the increase in temperature[91].

However, the wet process showed problems in terms of inhomogeneity and instability of such PMB. To solve these problems, American researchers proposed a "terminal process", which can be attributed to wet processes[92]. Unlike the traditional wet process, the final process is carried out at a higher temperature and longer mixing time, which causes desulfurization and depolymerization of the rubber crumb[88]. The obtained bitumen is characterized by a lower viscosity and homogeneity, thus, continuous mixing is not necessary so that the rubber particles are evenly distributed in the bitumen matrix[94].

2.3. Physical Modification of Bitumen with Thermoplastic Elastomers

Thermoplastic elastomers can resist permanent deformation under tension and recover elastically after the load is removed[95]. As a rule, thermoplastic elastomers used as bitumen modifiers are block-copolymers of alkenes and dienes. Styrene is used as an alkene, and butadiene or isoprene as dienes. The corresponding block copolymers are called styrene-butadiene-styrene (SBS), styrene-isoprene-styrene (SIS), styrene-ethylene/butylene-styrene (SEBS)[30,96].

The glass transition temperatures of the polystyrene block and the polybutadiene block are 95 °C and –80 °C, respectively[97]. The polystyrene block is rigid at high operating temperatures, contributing to strength, and the polybutadiene block, which has a rubber effect at low temperatures, provides an elastic recovery[30,95,96,98].

SBS molecules have a linear or radial structure. Linear SBS is characterized by two polystyrene blocks connected to polybutadiene, while in the radial structure, the polystyrene blocks form a radial configuration around the polybutadiene. The radial structure has been found to provide higher stability of the SBS/bitumen system (less delamination) and better elastic recovery[30].

Many studies have shown that the addition of SBS to bitumen increases SP and viscosity, with a slight decrease in P298, and also decreases FBP. Also, SBS reduces the intensity of the oxidation process simulated by short-term (RTFOT) and long-term aging, keeping the properties of primary bitumen almost unchanged[26,30,95,98,99].

The concentration of SBS plays a fundamental role in the PMB properties. Bitumen modification is carried out by adding up to 7 wt. % of SBS, and in some cases, different polymers can be used simultaneously. For soft and medium modification, the amount of polymer is up to 4.5 wt. %, for hard modification – more than 5 wt. %.

Despite many proven advantages of using SBS copolymers for bitumen modification, they are still far from perfect. For example, the homogeneity of the SBS/bitumen system is not always good, and storage instability of such PMB has been reported even for those containing low amounts of polymer[30,100]. An insufficient amount of light components causes the separation of phases in modified bitumen, a high content of aromatic substances is necessary for the production of homogeneous PMB. It is possible to improve the compatibility between SBS and bitumen with a low content of aromatic substances due to the addition of aromatic oil fractions (plasticizers). However, a too high content of aromatic substances (70–80 wt. %) in modified bitumen can lead to swelling and anti-plasticization (i.e., an increase in its glass transition temperature) of some polystyrene blocks, which adversely affects the final properties of modified bitumen. Lu and Isacsson[101] concluded that for bitumen containing 50–60 wt. % of arenes, modification with linear SBS provides the greater stability than those containing radial SBS.

3. Conclusions

Analysis of the current state of production of high-quality binding materials for road construction showed that their main production processes are deep vacuum distillation or oxidation of oil residues (tars) at oil refineries, followed by their physical modification with polymers. Modifying bitumen with polymers can be done at the refinery and enterprises of the road industry.

The main disadvantages of using distilled and oxidized bitumen are their low heat resistance and poor adhesion (adhesion) with traditional acidic mineral fillers, which, accordingly, causes the formation of ruts and cracking of asphalt concrete coatings using such binder materials, which in turn reduces the service life of such coatings. To solve these problems, physical (mechanical) modification of distilled and oxidized bitumen with polymers is carried out. As a rule, these are plastics processing waste (PE, PP, PET, and others) and block copolymers of the styrene-butadiene-styrene (SBS) type specially synthesized for this purpose. It is shown that the modification of bitumen, as a rule, takes place by dosing the polymer in the amount of 2–5 wt. %, at a temperature of 433–463 K for 1–3 hours. A large number of conducted studies have shown both the advantages and disadvantages of bitumen modification with polymers. The benefits are that physical modification improves elasticity recovery, resistance to cracking at low temperatures and resistance to rutting at high temperatures. The disadvantages include thermal instability and problems with the homogeneity of the obtained PMB. These disadvantages can be partially eliminated by chemical modification processes, in which a chemical agent is used to change the properties of the binder due to its interaction with the constituent parts of bitumen. Chemical modification processes will be described in report 2 of this study.

Abbreviations

ABS Acrylonitrile-butadiene-styrene
ACM Asphalt concrete mixture
BE Bitumen emulsions
CLNR Coagulated (solid) natural rubber
D298 Ductility at 298 K (cm)
E298 Elastic recovery at 298 K (%)
EVA Ethylene-vinyl acetate
FBP Fraas breaking point (K)
HDPE High-density polyethylene
IP800 Penetration index is calculated from the softening point at which the penetration is equal to 800
KVS Coal tar
LDPE Low-density polyethylene
MDPE Medium density polyethylene
NR Natural rubber
NRL Liquid natural rubber
P298 Penetration at 298 K (dmm)
PE Polyethylene
PET Polyethylene terephthalate
PMB Polymer modified Bitumen
PP Polypropylene
PS Polystyrene
PU Polyurethane
PVC Polyvinyl chloride
SBS Block copolymer styrene-butadiene-styrene
SEBS Block copolymer styrene-ethylene/butylene-styrene
SIS Block copolymer styrene-isoprene-styrene
SP Softening point (K)

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ОГЛЯД МЕТОДІВ МОДИФІКУВАННЯ ДОРОЖНІХ БІТУМІВ. ЧАСТИНА 1 – ФІЗИЧНЕ МОДИФІКУВАННЯ

Анотація. *Інформація в цьому дослідженні була зібрана на основі ретельного огляду останніх статей, пов'язаних із одержанням в'яжучих матеріалів для дорожнього будівництва і покращенням їхніх експлуатаційних властивостей. Зосереджено увагу на фізичному модифікуванні дорожніх бітумів полімерними модифікаторами. Показано вплив трьох основних типів полімерів (термопластів, еластопластів і термоеластопластів) на основні фізико-механічні властивості бітум-полімерних композицій. Встановлено основні технологічні параметри й особливості фізичного модифікування бітумів різними типами полімерних модифікаторів.*

Ключові слова: *бітум, фізичне модифікування, термопласти, еластопласти, термоеластопласти.*