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ESTIMATING THE EFFECT OF AQUEOUS CATIONIC LATEX FROM THE CLASS OF THERMAL ELASTIC PLASTICS ON THE PROPERTIES OF BITUMEN EMULSIONS

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To produce cationic bitumen emulsions, bitumen is used, whose penetration is not lower than 90 mm^{-1}. Such bitumen has a small plasticity interval, which leads to a deterioration in its heat resistance at elevated temperatures and narrows the scope of application of emulsions based on it.

Based on the review of emulsion modification methods, the modification has been proposed that involves mixing the finished bitumen emulsions with aqueous cationic latex.

The process of interaction between a bituminous emulsion and an aqueous cationic latex has been considered. A mechanism for the disintegration of the modified bitumen emulsion on the surface of mineral materials was proposed. The emulsifiers have been selected and the composition of the aqueous phase has been chosen based on the analysis of surface tension isotherms. The influence of the modification on the properties of bitumen emulsions was investigated.

It was established that the main physicochemical characteristics of the interphase surface accept similar values for the aqueous phase and emulsions based on it.

It has been proven that the introduction of aqueous cationic latex quite moderately affects the basic physical-mechanical properties of emulsions, which makes it possible not to change the main technological parameters when using them.

It was established that increasing the concentration of the polymer in the emulsion has a positive effect on the physical-mechanical properties of the binder. With an increase in the concentration of the polymer to 6 % the softening temperature increases by 16 °C, elasticity is 74 %, and the holding capacity at minus 25 °C is approaching 100 %.

Improving the physical-mechanical properties of residual binder as a result of emulsion modification could increase the durability of layers in a roadbed based on bitumen emulsions and expand the scope of their application in the construction and repair of motorways

Keywords: bitumen emulsions, aqueous cationic latex, surface tension, polymers, softening temperature

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1. Introduction

For many years, cationic road bitumen emulsions have been successfully used in various technologies in the construction and repair of motorways in many countries. The key to arranging a high-quality and durable roadbed layer based on bitumen emulsions is the combination of the optimal physical-mechanical properties of emulsions and the residual binder. Optimal physical-mechanical properties refer to those properties that meet the requirements for a particular technology, namely, ensure the necessary decay time, viscosity, uniformity, stability during transportation and storage. For the binder, optimal is to ensure heat resistance and water resistance in the operation of roadbed layers based on bitumen emulsions.

To produce cationic bitumen emulsions, bitumen is used, whose penetration is not lower than 90 mm^{-1}. Such bitumen has a small plasticity interval, which leads to a deterioration in its heat resistance at elevated temperatures and narrows the scope of emulsions based on it. One of the directions to improve the structural and mechanical properties of residual binder is the introduction of polymeric substances into its composition. Features in the composition design, the manufacture, and the physical-mechanical properties of cationic road bitumen emulsions modified by polymers, as well as the binder released as a result of their decay, have remained insufficiently studied up to now.

Thus, it is a relevant task to improve the properties of cationic bitumen emulsions by modifying them with aqueous cationic latex and to study the influence of various factors on the properties of the emulsions and residual binder.

2. Literature review and problem statement

To expand the application scope of cationic bitumen emulsions and increase the durability of roadbed layers based on bitumen emulsions, it is advisable to improve the properties of the residual binder. To improve the properties of the residual binder, polymers must be introduced in the emulsion composition. Introducing polymers of different types differently affects the physical-mechanical properties of bitumen, namely, an increase in the softening temperature, a decrease in penetration, and an elasticity indicator [1]. The same polymers [2] are used to modify bitumen emulsions. Based on the analysis reported in [1, 2], the main types of polymers used in road construction were distinguished (Fig. 1).

Paper [3] suggests three main ways of injecting a polymer into the emulsion: pre-mixing bitumen with a polymer, adding aqueous latex during emulsification, adding latex to the finished bitumen emulsion. It should be noted that each technique has its advantages and disadvantages.

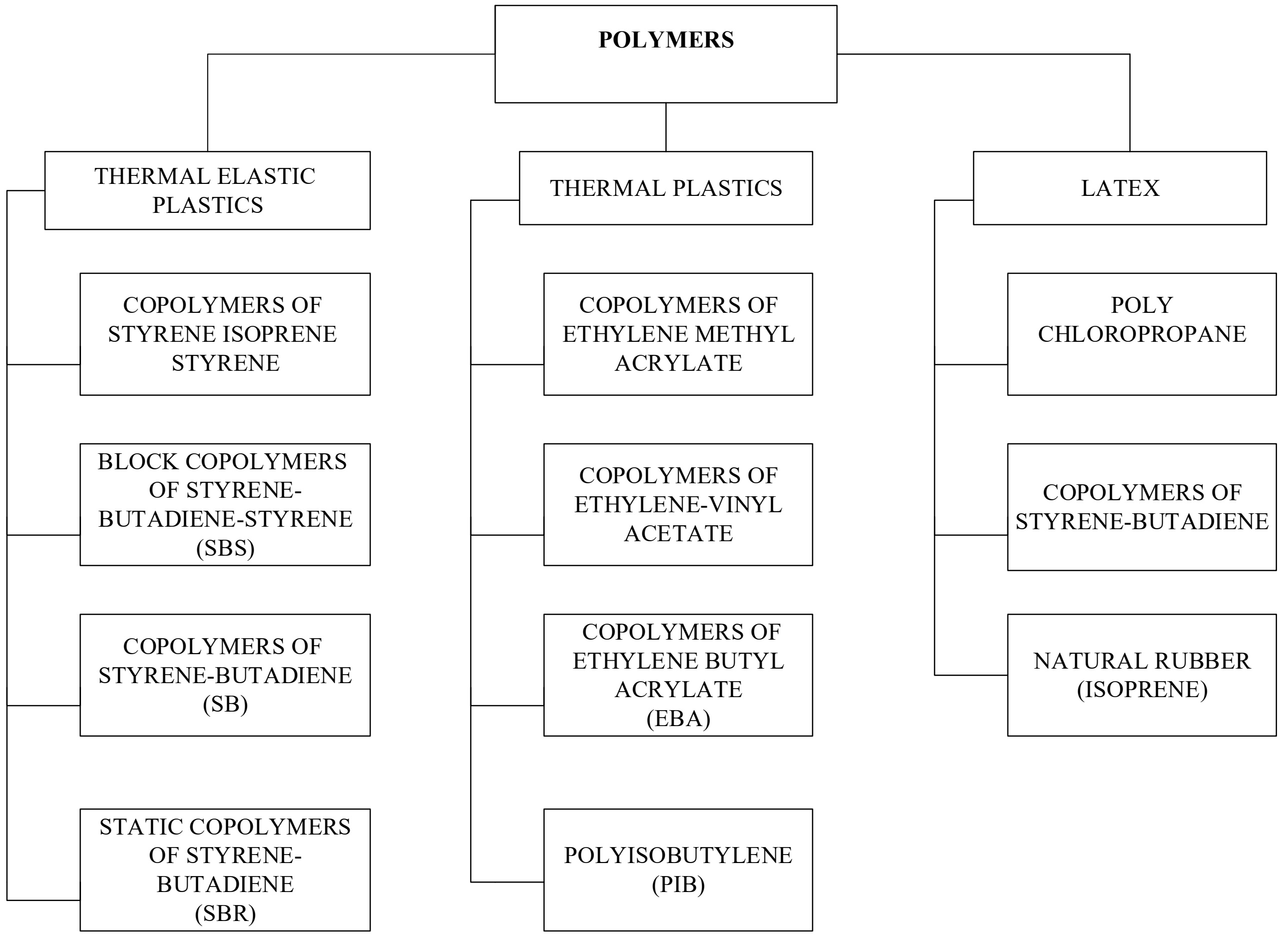

Fig. 1. Basic types of polymers used in road construction

When introducing a polymer into the starting bitumen, it is necessary to have special mixers to ensure the effective mixing of bitumen with the polymer. In addition, it is necessary to maintain the heating temperature of the modified binder at the level of 160–180 °C, to ensure the viscosity required for emulsification. The temperature of the aqueous phase, depending on the solubility of the emulsifier in water, can vary from 40 °C to 80 °C. Due to the fact that the total temperature should not be above 200 °C, emulsification must be carried out under pressure; a cooling system should be installed on the line for transporting the finished emulsion. In addition, modified bitumen-based emulsions have a wide dispersion curve, which is characterized by a smaller average droplet diameter. As a result, emulsions modified in this way have less viscosity and a greater probability of coagulation during storage.

Adding an aqueous solution of latex during emulsification can be performed by mixing with water, introducing it into the mixer for the aqueous phase, and feeding to the mixer as an independent ingredient. In all these cases, high-quality mixing of latex and components of bitumen emulsion is provided.

The disadvantage of this administration technique is the need for additional dosing devices for latex feeding and regular cleaning of the latex feed line to prevent its coagulation in the pipes.

The third technique to obtain a modified emulsion is to inject aqueous latex directly into the finished warm or cold emulsion by simply mixing the latex and emulsion until a modified bitumen emulsion with the required polymer content is received.

The first two techniques are often used to modify bitumen emulsions. Studies [4–6] examine the effect of modification based on methods 1 and 2 on the properties of emulsions and residual binder. Paper [4] investigates the effect of latex SBR modification; work [5] – NBR latex; study [6] – X-SBR latex.

A study into the properties of binders released from emulsions modified by different types of polymers [7] shows that a greater value of the softening temperature is inherent in the binder modified by SBR polymer, followed by SBS and poly chloropropene. The elasticity indicator for twisting for the binder released from the emulsion modified by SBS is 20 %, from the emulsion modified by poly chloropropene – 16.2 %, SBR – 10 %, EVA – 9.4 %. Analysis of the results of the loss assessment during abrasion of water-saturated samples (Wet Track Abrasion test, WTAT) reveals that, based on increasing losses during abrasion, the emulsions were arranged as follows: emulsion modified by SBR, SBS, polychloropropylene, natural latex, EVA. In terms of the increased amount of sand (%) and track depth (Loaded Wheel Test, LWT), the emulsions are arranged as follows: modified by SBR, natural latex, SBS, EVA, polychloropropylene. According to the results from the analysis of the holding capacity of a binder film based on the method of Violite, the best holding capacity is inherent in the emulsions modified by SBR, SBS, and EVA polymers, compared to the holding capacity of emulsions modified by poly chloropropene. In general, the best results were demonstrated by the emulsions modified by the polymer of an SBR type.

A study into the effect of emulsion pre-modification with SBS latex and post-modification with SBR latex on the properties of residual binder is reported in paper [8]. According to the results of the study, the modified binder, regardless of the modification technique, was characterized by better indicators of properties compared to the unmodified one.

The effect of modification by adding the latex SBR to the finished emulsion on the properties of the emulsion was considered in [9]. However, there are no description of the structure of the resulting system and the mechanism for the disintegration of the modified emulsions in the cited work.

The structure of the emulsion and the mechanism of its disintegration from the point of view of colloidal chemistry are described in detail in paper [10] for the emulsions modified by the polymer, according to techniques I and II in work [11], for that modified in line with technique III – in an earlier study [12].

The thermodynamic characteristics of moistening the surface of mineral materials with bitumen were considered in paper [13], the surface properties of aqueous solutions of emulsifiers – in work [14] and in an earlier published study [15]. However, the issue of the effect of aqueous cationic latex, when it is introduced into the finished emulsion, on the thermodynamic properties of emulsions remains unresolved.

All this suggests that it is advisable to conduct a comprehensive study into the effect of modification of the finished emulsion with aqueous cationic latex on the processes of structure formation, the thermodynamic properties, physical-mechanical properties of cationic bitumen emulsions and the residual binder.

3. The aim and objectives of the study

The aim of this study is to adjust the properties of cationic bitumen emulsions by modifying them with aqueous cationic latex in order to increase the durability of roadbed layers and expand the scope of emulsion application.

To accomplish the aim, the following tasks have been set:

– to theoretically substantiate and experimentally confirm the features of the influence of aqueous cationic latex on the processes of structure formation and the thermodynamic properties of cationic bitumen emulsions based on various emulsifiers;

– to investigate the influence of aqueous cationic latex on the physical-mechanical properties of bitumen emulsions and describe the mechanism of their decay on the surface of mineral materials, and propose a mechanism for the decay of modified emulsions on the surface of mineral materials;

– to investigate the effect of an aqueous cationic latex supplement to bitumen emulsions on the properties of the residual binder.

4. The study materials and methods

4. 1. The materials adopted to assess the effect of modification of bitumen emulsions with aqueous cationic latex

During our research, the oil road bitumen of brand BND 70/100 was used for the preparation of emulsions; its basic physical-mechanical properties are given in Table 1. In addition, we also used cation-active emulsifiers manufactured by "CECA Arkema group" (France) and "AkzoNobel" (the Netherlands). To neutralize emulsifiers, hydrochloric acid with a density of 1.163 g/cm^3 and a concentration of 33 % was used; for modification – the aqueous cationic latex Butonal NS 198, manufactured by BASF SE (Germany).

To determine the emulsion decay index, quartz sand with the following chemical composition was used: the SiO_2 content is 99.8 %, Al_2O_3 – 0.15 %, Fe_2O_3 – 0.05 %. The granulometric composition of sand is given in Table 2.

Table 1

The physical-mechanical properties of starting bitumen

Indicator name	Value		Test method
	for starting bitumen	for the original bitumen diluted with 2 % kerosene	
Penetration, 0.1 mm: at a temperature of 25 °C,	73	112	DSTU EN 1426
at a temperature of 0 °C	21	22	DSTU EN 1426
Softening temperature, °C	48	46	DSTU EN 1427
Ductility at a temperature of 25 °C, cm	>100	>100	DSTU 8825
Adhesion to glass surface, %	15	12	DSTU B V.2.7-81
Property change upon warming: – mass change upon warming, %	0.2	0.4	DSTU EN 12607-2
– residual penetration, %	98	80	DSTU EN 12607-2
– softening temperature change, °C	5	5	DSTU EN 12607-2
Penetration index	–0.4	–0.12	DSTU 8859

Table 2

Sand granulometric composition

Material	Passing a sieve, the size of, %						
	2.5	1.25	0.63	0.315	0.14	0.07	<0.071
Quartz sand	100.00	100.00	100.00	96.72	7.38	0.00	0.00

Granite gravel with cube-shaped fractions of 5–10 mm and 20–40 mm was used to determine the physical-mechanical properties of emulsions.

4. 2. Methods and equipment used in the research

Cationic bitumen emulsions were prepared at the laboratory installation designed by the plant "Ukrbudmash" (Ukraine).

To perform experimental studies, both standard methods for exploring cationic bitumen emulsions and bitumen and a series of special methods and devices were used.

The physical-mechanical properties of bitumen emulsions were determined according to DSTU B V.2.7 129 [16].

The surface tension of aqueous solutions and emulsions at the liquid-gas interphase was evaluated on the basis of maximum pressure in a bubble using a micromanometer.

We determined the edge angle of wetting the emulsifiers with aqueous solutions and the glass surface with bitumen road cationic emulsions by lying droplets on the surface of the solid with the help of a projection device.

The Violite method was applied to determine the holding capacity of the binder, released from road cationic bitumen, and the modified bitumen emulsions.

According to the recommendations given in work [17], the tests were carried out at negative temperatures from 0 °C to minus 25 °C.

The procedure of water evaporation to obtain residual binder was carried out in line with the California Test 331 "Method of testing for residue by evaporation of latex modified asphalt" [18].

To assess the reliability of our results, the measurement error assessment was carried out by calculating the root mean square deviation and the confidence interval.

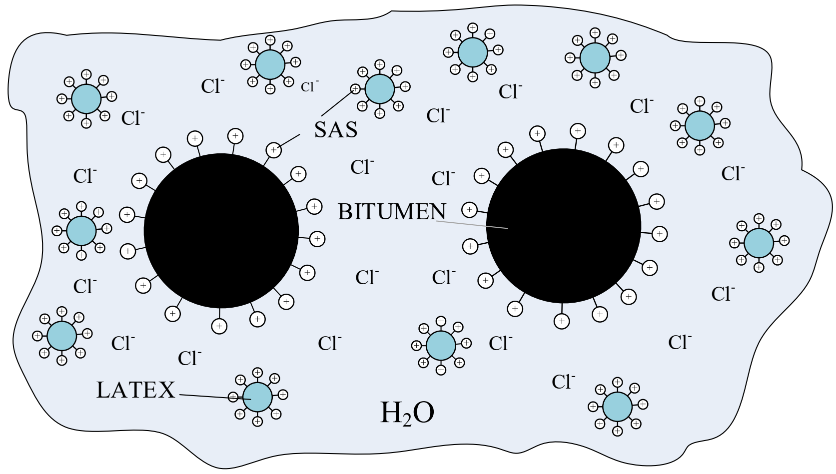

Fig. 2. Schematic image of the structure of the cationic bitumen emulsion modified by cationic latex

5. Results of studying the effect of aqueous cationic latex on the properties of cationic bitumen emulsions

5. 1. Examining the effect of aqueous cationic latex on the thermodynamic properties of cationic bitumen emulsions

Latex is a water dispersion of a high polymer in water. Latex is obtained by emulsion polymerization in water. Aqueous cationic latexes have a similar structure, from the point of view of colloidal chemistry to cationic bitumen emulsions. Stability in both systems is ensured by saturated or close to saturation adsorption layers of oriented molecules of SAS-emulsifiers and by a double electric layer around each bitumen or latex particle (micelle nucleus). Increasing the concentration of a SAS emulsifier causes an increase in the density and strength of the adsorbing layers around bitumen (latex) particles. The increase in the concentration of SAS in a dispersion environment contributes to the increased stability and homogeneity of both bitumen and latex emulsions. The outer layer of the micelle is formed by chlorine ions, or when using another acid, the corresponding ions of the acid residue.

When introducing aqueous cationic latex to the finished emulsion, a homogeneous distribution of bitumen and latex micelles, which have the same charge, occurs in the volume of the aqueous phase (Fig. 2).

According to the proposed structure of the modified emulsion, introducing additional SAS in the system may lead to a decrease in the surface tension and the edge wetting angle.

Regarding the physical-mechanical properties, there could be an increase in the indicator of homogeneity and a deterioration in the stability during storage and transportation.

To select the composition of emulsions, we first analyzed the adsorption isotherms of emulsifiers at different temperatures and with different pH. Based on the analysis, the following emulsifiers were chosen for further research: Dinoram SL, Polyram L80 (CECA, France), and Redicot RM007, Redicot E11 (AkzoNobel, the Netherlands). The selection criterion was the value of CCM and solubility in water. Surface tension isotherms for the selected emulsifiers at pH=2 are shown in Fig. 3.

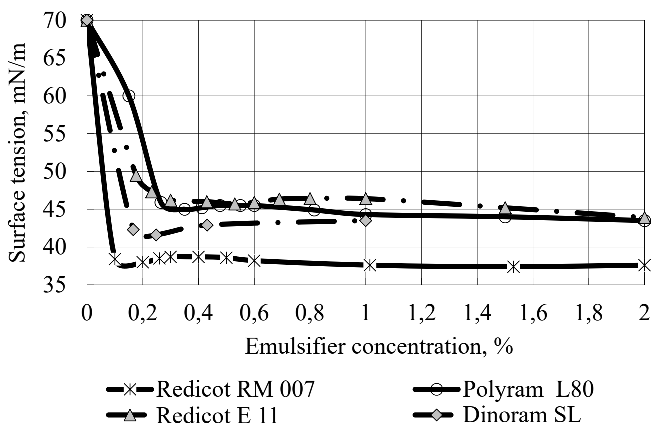

Fig. 3. Isotherms of the surface tension of blending at pH=2

Our analysis of the physical and chemical characteristics of the interphase surface for the aqueous phase, bitumen, and modified bitumen emulsions (Fig. 4) has revealed that their value is influenced to a greater extent by the nature and concentration of the emulsifier. 25–30 words.

According to our results, the solutions and emulsions based on the Redicot RM007 emulsifier (the Netherlands) are characterized by lower values of the surface tension and the edge wetting angle formed by the liquid on the surface.

According to the above results, we can conclude that the selection of the type of emulsifier and its concentration can be carried out based on the analysis of the physicochemical characteristics of the interphase surface for the aqueous phase.

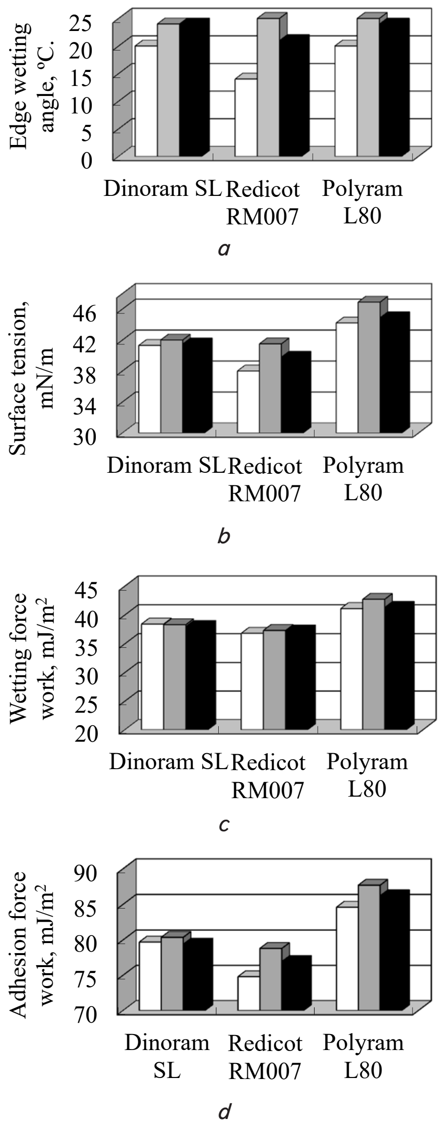

Fig. 4. Physical and chemical characteristics of the interphase surface: *a* – edge wetting angle; *b* – the surface tension of solutions; *c* – the work of wetting forces, *d* – the work of adhesion forces. Aqueous phase – white color, cationic bitumen emulsion – gray; cationic bitumen modified emulsion – black

The study results have shown that the introduction of thermoplastic polymers into the cationic bitumen emulsions exerts a rather moderate effect on the main indicators of the thermodynamic properties of emulsions.

5. 2. Investigating the influence of aqueous cationic latex on the physical-mechanical properties of cationic bitumen emulsions

One of the most important technological characteristics of bitumen emulsions was investigated – breaking index. It is this characteristic that largely determines the possibility of using a bitumen emulsion in a particular technology. Factors that influence the rate of decay can be divided into three groups: the composition of the emulsion, the nature and dispersion of mineral materials, the temperature of emulsions and the environment.

The mechanism of disintegration of the finished bitumen emulsion modified by latex has been designed.

First of all, water and hydrogen ions are adsorbed on the surface of acidic mineral materials, which are in the aqueous phase of the emulsion. In parallel, there is gradual adsorption of emulsifiers, first free, then latex emulsifiers and bitumen emulsion emulsifiers.

The next step is to form a bond between the active centers of mineral material and acid with the emulsifier due to the electrostatic orientational gravity of the negatively charged surface and positively charged polar groups of the emulsifier. As a result of emulsifier adsorption, the surface is gradually turned hydrophobic with carbon "tails" of the emulsifiers. At the same time, due to the interaction of an acid with the surface of mineral materials, the acidity of the solution drops. In a neutral environment, cation-active emulsifiers lose the ability to dissolve, which leads to their complete adsorption on the surface of mineral materials.

At the next stage, due to the adsorption of the emulsifier and the drop in acidity, the droplets, of both bitumen and latex, lose their protective shells and first merge, and then settle on the hydrophobic surface of mineral materials. After the loss of the protective layer from the emulsifier, the polymer droplets are merged and, as a result of hydrophobic gravity, form a cellular structure around the drops of bitumen. A mixed coagulant is formed, depositing on the mineral particles' surfaces (Fig. 5).

A small part of the water from the emulsion is absorbed by the surface of mineral materials, the rest of the water is gradually squeezed out with bitumen with an emulsifier, and evaporates.

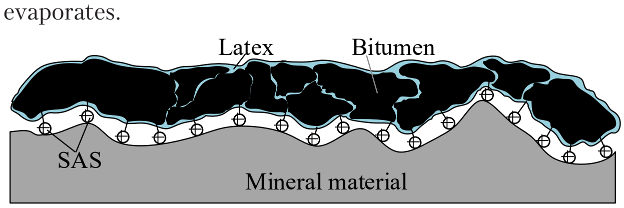

Fig. 5. Schematic image of the decay of a bitumen emulsion modified by aqueous cationic latex

Our experimental studies have confirmed the proposed mechanism of emulsion decay (Fig. 6).

The introduction of aqueous latex into the emulsion composition caused an insignificant slowdown in decay, which can be explained by the proposed mechanism – the decay time increased due to the time for latex and its SAS settling.

A higher breaking index at the same emulsifier concentration was inherent in the emulsions based on the Dinoram SL emulsifier, which has a simpler molecular structure (a derivative of n-alkyl propylene diamine). The diffusion of volumetric cations of alkyldiaminethoxylate (Redicot RM 007) and polyamines (Polyram L80) to the surface of mineral material proceeded more slowly.

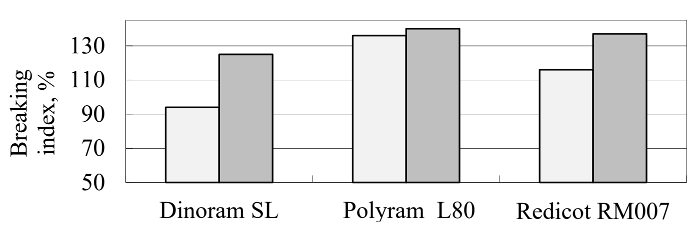

Fig. 6. Impact of modification on the breaking index

One of the important technological characteristics of the emulsion is homogeneity, which is defined as the percentage of residue on a sieve of a certain size; in Ukraine, in accordance with the national standard DSTU B V.2.7–129, the sieve size is 0.14 mm.

The results of our study (Fig. 7) have shown that with an increase in the concentration of the emulsifier, the homogeneity indicator decreases and stability in the storage of emulsions increases. This is due to the fact that with an increase in the concentration of the emulsifier, surface tension decreases, and the dispersion of bitumen and the formation of smaller particles are improved. In addition, with an increase in the concentration of the emulsifier, the density and strength of the adsorbing layers around bituminous particles increases, which also contributes to the improved stability and homogeneity of emulsions.

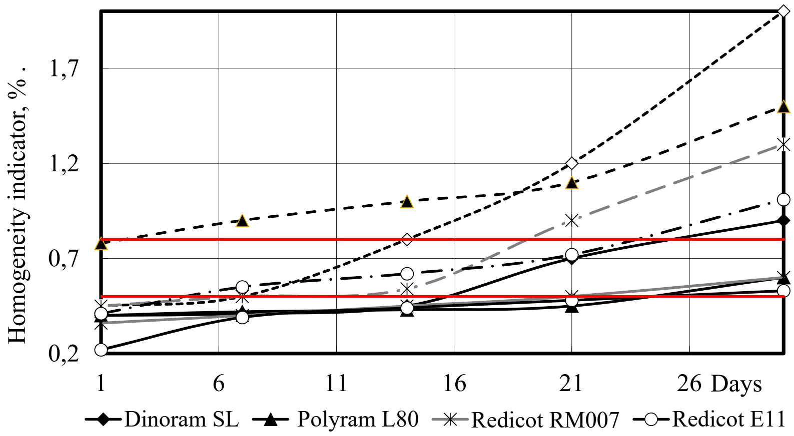

Fig. 7. Impact of modification on stability during storage: solid lines – cationic bitumen emulsions; dotted lines – cationic bitumen modified emulsions

According to the results obtained, all cationic bitumen emulsions (CBEs) based on different emulsifiers at the same concentrations, when compared to cationic bitumen modified emulsions (CBMEs), demonstrate significantly better stability indicators during storage. However, it should be noted that even with the deterioration of the homogeneity indicator, the studied modified emulsions did not disintegrate on day 30.

With an increase in the concentration of aqueous latex, no significant changes in the physical-mechanical properties of emulsions occurred (Table 3).

Table 3

Effect of modification by aqueous cationic latex on the physical-mechanical properties of bitumen emulsions

Property indicator name	Concentration of Butonal NS 198 by bitumen weight, %				
	0	1.5	3	4.5	6
Conditional viscosity at a device with a hole diameter of, at a temperature of 25 °C, s	9	9.5	10	9.5	9
Homogeneity (residue on sieve No. 0.14), %	0.3	0.35	0.4	0.4	0.4
Hydrogen ion concentration indicator, pH	2	2.2	2.3	2.3	2.3
Indicator of adhesion between the binder released from an emulsion and gravel surface, %	90	92	93	95	98
Breaking index, %	252	258	260	260	260

There is also an improvement in the indicator of adhesion to the surface of the granite gravel with a fraction of 20–40 mm compared to the starting emulsion. That can be explained by the presence of additional SAS in latex.

5. 3. Investigating the effect of an aqueous cationic latex supplement to bitumen emulsions on the properties of residual binder

We studied the effect of the introduction of aqueous cationic latex into the composition of the emulsion in the amount of 3 % by the weight of bitumen (Fig. 8) on the properties of the residual binder. The results showed that the released binder is characterized by higher values of the softening temperature, slightly lower values of the penetration indicator, and the manifestation of elasticity.

We studied the effect of modification on the holding capacity of a bitumen film at low temperatures determined by the method of Violite (Fig. 9). The results showed that the modified emulsions based on different emulsifiers at all temperatures and under different test conditions demonstrated significantly better results.

It was found that an increase in the concentration of the polymer in the emulsion composition leads to a further increase in the temperature of softening and holding capacity at low temperatures, determined by the method of Violite, and a slight increase in the elasticity indicator (Tables 4, 5).

Table 4

Physical-mechanical properties of the binders released from modified bitumen emulsions at different concentrations of the cationic aqueous latex Butonal NS 198

Property indicator name	Concentration of Butonal NS 198 per bitumen weight, %				
	0	1.5	3	4.5	6
Penetration, 0.1 mm, at a temperature of					
25 °C	86	80	78	70	60
0 °C	28	28	27	27	27
Softening temperature, °C	47	52	54	58	63
Ductility, at a temperature of 25 °C, cm	60	50	45	45	40
Elasticity, %	10	65	68	74	74
Penetration index	–0.19	0.07	0.65	1.18	1.42
Adhesion to glass surface, %	92	94	95	95	97

Table 5

The holding capacity of a bitumen film at different temperatures

Concentration of Butonal NS 198 per bitumen weight, %	Test temperature, °C		
	–5	–10	–25
0	88	52	30
1.5	94	71	35
3	95	90	57
4.5	99	96	73
6	100	98	95

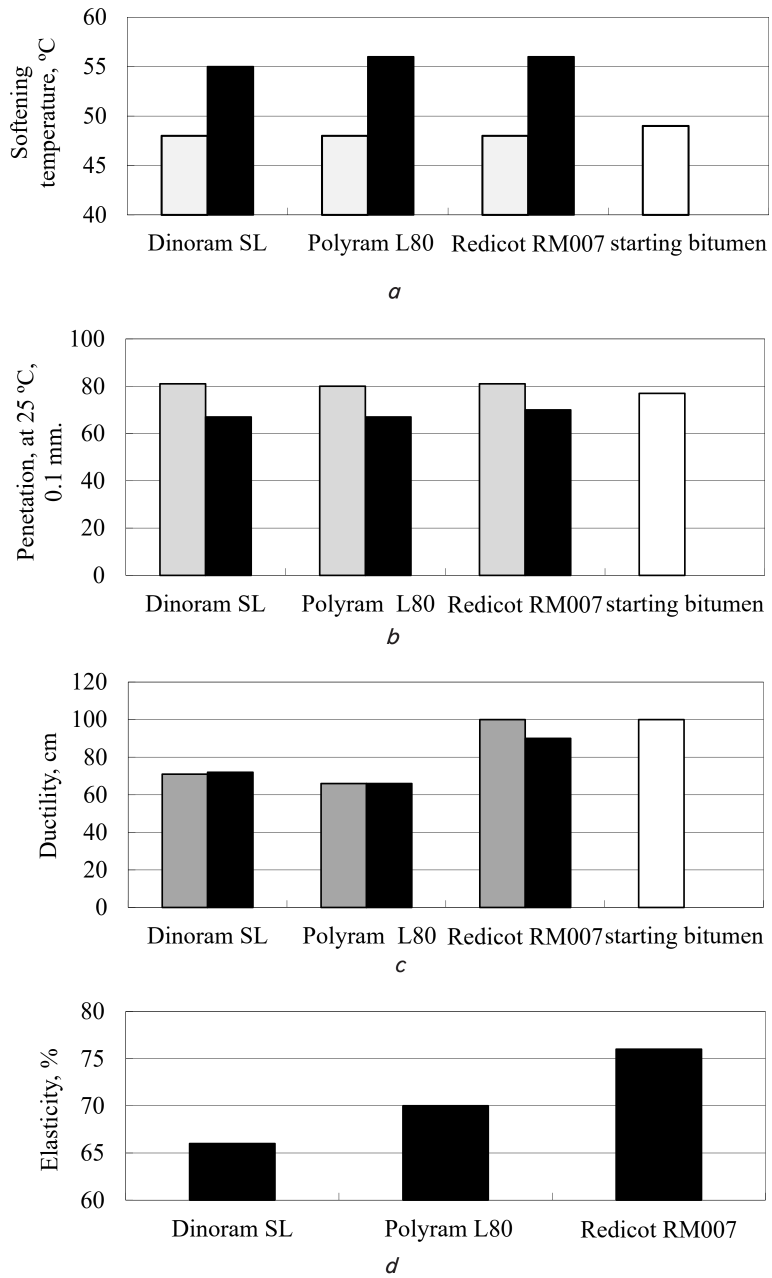

Fig. 8. The effect of modification on: *a* – the temperature of softening; *b* – penetration; *c* – ductility; *d* – the elasticity of residual binder at 25 °C; gray color – cationic bitumen emulsions; black color – cationic bitumen modified emulsions; white color – starting bitumen

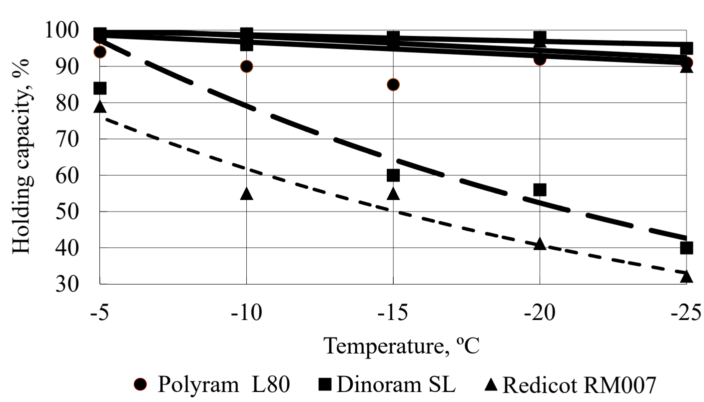

Fig. 9. Effect of temperature and modification on the holding capacity of the residual binder. Solid lines – cationic bitumen modified emulsions; dotted lines – cationic bitumen emulsions

With an increase in the concentration of the polymer as part of the polymer emulsion up to 6 % the softening temperature increases by 16 °C, elasticity is 74 %, and the holding capacity at minus 25 °C is approaching 100 %.

6. Discussion of results of studying the effect of aqueous latex on the properties of bituminous emulsions and residual binder

A comparative assessment of the physical and chemical characteristics of the interphase surface for the aqueous phase of bitumen and modified bitumen emulsions (Fig. 3, 4) has shown that the nature and concentration of the emulsifier most significantly influenced these indicators. Analysis of the surface properties of aquatic phases can be used for the comparative evaluation of emulsifiers at the stage of selection of the composition of the emulsion.

Modifying the finished emulsion with aqueous cationic latex did not significantly affect the thermodynamic properties of the emulsion. These two balanced colloidal systems worked as a whole (Fig. 2).

The proposed structure and mechanism of decay (Fig. 5) were confirmed by the results of our experimental studies. The analysis of the physical-mechanical properties of bitumen and modified bitumen emulsions based on various emulsifiers (Fig. 6, 7, Table 3) has revealed that the modification of finished bitumen emulsions did not significantly affect their physical-mechanical properties. There was an insignificant deterioration in the homogeneity and stability during storage and a small increase in the emulsion decay time.

Minor changes in the physical-mechanical properties of emulsions allowed us to assert that there is no need to change technological aspects when applying a modified emulsion instead of a regular bitumen emulsion. At the same time, we obtained a residual binder with much better properties, namely, the softening temperature increased by 5 °C already with the introduction of 1.5 % of the polymer by the weight of bitumen, the binder acquired elasticity at the level of 65 % (Fig. 8, 9, Tables 4, 5).

Rational is the concentration of polymer from 3 % to 4.5 % by weight of bitumen. Further increase in concentration when assessing the price/quality ratio does not produce significant changes in the temperature of softening and elasticity.

The disadvantage of dispersing latex in the finished emulsion is a slight decrease in the uniformity of the emulsion. The advantages include the lack of additional capacity to preserve the modified emulsion and the possibility of its manufacture in the required volumes immediately before use.

The considered modification technique makes it possible to improve the quality of the bitumen binder at minor additional measures.

7. Conclusions

1. Modifying emulsions with aqueous cationic latex causes a slight decrease in the surface tension, the edge wetting angle, and the work of wetting forces and adhesion forces. The basic physicochemical characteristics of the interphase surface between the aqueous phase and emulsions based on it (edge wetting angle, surface tension, the work of adhesion forces, the work of wetting forces) accept close values. The substantiation of the emulsifier selection can be carried out based on a comparative analysis of the physical and chemical characteristics of the interphase surface of the aqueous phase under laboratory conditions.

2. The introduction of thermoplastic polymers into the composition of cationic bitumen emulsions leads to minor changes in the physical-mechanical properties of emulsions. The homogeneity index deteriorates by an average of 0.52 % on day 30, slowing down the decay from 4 % to 31 %.

3. The presence of a polymer in the amount of 3 % by binder weight significantly affects the physical-mechanical properties of the residual binder. The softening temperature increases by an average of 8 °C, elasticity is 71 % on average, while the holding capacity increases at minus 25 °C by 68 % on average. Increasing the concentration of the polymer in the emulsion has a positive effect on the physical-mechanical properties of the binder. With an increase in the concentration of the polymer to 6 % the softening temperature increases by 16 °C, elasticity is 74 %, and the holding capacity at minus 25 °C is approaching 100 %.

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