Magazine of Civil Engineering

ISSN 2712-8172

journal homepage: http://engstroy.spbstu.ru/

DOI: 10.34910/MCE.106.7

Nanomodified rejuvenators and protective materials for asphalt concrete

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Keywords: nanomodification, carbon nanofiber, protection, rejuvenation, asphalt concrete

Abstract. One of the effective methods to prevent the destruction of asphalt concrete pavement is to treat it with protective and rejuvenator materials. This study is aimed at developing an effective composition of the protective material. The proposed method for studying the effect of modification according to the results of rheological tests allows us to determine the conditional elastic modulus of the structured liquids. The influence of the degree of modification on the content of oil-polymer resins in the bitumen binder was evaluated using the developed quality criterion considering the modifier content contribution. We selected a solvent that provides effective dispersion and stability of the resulting suspension. The studied nanomodifier in the composition rejuvenator material had an impact on the properties of asphalt concrete increasing its crack resistance by 49 %, water resistance by 11 %, and shear adhesion by 6.1 %.

1. Introduction

Highways are an important part the country's road infrastructure and significantly affect its socio-economic development. A constant increase in vehicle traffic intensity leads to a significant acceleration in the wear road surfaces, which leads to an increase in the volume repair and restoration work [1, 2].

An effective method for preventing the progressive destruction asphalt concrete pavement is its treatment with protective-reducing rejuvenating compositions [3–4]. The main purpose of using such compositions is the formation a strong protective layer that penetrates deeply into the volume the road composite, which ensures the clogging the pore space, and is resistant to liquid media (water, solutions of various chemical agents) [5].

The first foreign studies of rejuvenator compounds date back to the 70s of the XX century [6]. So, American researchers in the period from 1971–1975 studies have been conducted to establish the penetration depth some rejuvenator compounds in the dense surface asphalt concrete pavement. Depth was estimated by penetration and viscosity of bitumen extracted from asphalt concrete samples. Another independent study [7] showed that the “rejuvenator agent” significantly reduced the complex elastic modulus asphalt concrete samples with a residual porosity of 10–12 %. This result was the basis for recommendations on the prohibition of rejuvenator agents on asphalt pavement with a residual porosity of less than 7–8 %.

C. Chiu and M. Lee [8] studied several different types rejuvenator: traditional impregnations, impregnations based on reconstituted asphalt binder and emulsion impregnations. All studied rejuvenator showed an increase in the ductility “old” binder in the upper layer of asphalt concrete pavement at a depth of 1 cm. The drying speed of the asphalt pavement treated with impregnations also depends on their composition and varies from 2 to 7 hours.

J. Lee and J.R. Kim [9] found that rejuvenator significantly affect the micro- and macro-texture surface of roads and are able, depending on the type modified binder used in the composition, to reduce the adhesion wheel to the road surface by 24 %.

Shekhovtsova, S.Yu., Korolev, E.V. Nanomodified rejuvenators and protective materials for asphalt concrete. Magazine of Civil Engineering. 2021. 106(6). Article No. 10607. DOI: 10.34910/MCE.106.7

Ambiguous results were obtained by J. Lee et al. [10] according to which the use rejuvenator reduces the complex dynamic elastic modulus and the phase angle of compacted asphalt concrete, increases the track depth and creep strain, and reduces the car tire resistance to sliding along asphalt surface. However, it was also established that the use rejuvenator can effectively resist chipping and “washing out” of individual grains stone material from the road surface.

Summarizing the existing studies, we can conclude that one of the disadvantages existing protective and rejuvenator materials [5–15] used for the surface treatment asphalt concrete coatings is a decrease in the adhesion automobile wheels to the road surface, insufficient resistance to abrasion due to low adhesion, their low fluidity (high viscosity) at operating ambient temperatures, which reduces their penetration rate into the structure asphalt concrete. In this regard, it is currently relevant to use liquid compositions based on bitumen, which use organic solvents with additional modifiers.

Domestic research in this direction is mainly aimed at selecting the optimal ratio the components of the impregnating composition [16–17]. The Russian market of solvent-based protective and reducing rejuvenating materials (RM) is represented by a wide range products: Silcoat (RF), Dorsan (RF), PS-1 (RF), Sanad (RF), Brit-RM-R (RU), Biguma – LDGA (Germany), Surtreat PDC (USA), CRF, Reclamite, CRF Crafco (USA) and others, which testifies to the interest of the road industry in these materials and, at the same time, the lack of domestic research aimed at studying the effect component the composition and technological processes for the preparation of RM on the properties of asphalt concrete. Naturally, the accumulation of knowledge and experience will eliminate the existing problems in this area.

This research work is aimed at developing the composition an effective nanomodified rejuvenating material combined action.

2. Materials and Methods

The development and optimization of an effective nanomodified rejuvenating material (RM) includes the following steps:

1. Development and optimization of modified bitumen binder (bitumen binder and petroleum polymer resin);

2. Development and optimization of nanomodified suspension (organic solvent and nanofiber);

3. Development and optimization of the control composition of the rejuvenating material (modified bitumen binder prepared according to steps 1 and organic solvent);

4. Nanomodification of the control composition of the rejuvenating material prepared according to steps 3.

The experimental method was used to develop the nanomodified composition RM, the analytical method was used to optimize the composition RM.

For first step was used bitumen BND 90/130, manufactured by LLC Lukoil and petroleum polymers resins (PPR) which are low molecular weight thermoplastic polymer obtained by polymerization aliphatic and aromatic hydrocarbon fractions. Petroleum polymer resins (PPR) were considered as a modifying component for a bituminous binder. Two petroleum polymer resins were considered: PPR Pyroplast-2K which is a product of pyrolysis fraction C9 at 125–200 °C with thermal polymerization containing polycyclopentadiene, polystyrene; PPR Inden-Kumaron which is a product thermal and / or catalytic polymerization the C9 fraction at 120–210 °C hydrocarbon pyrolysis products at a temperature of 240–250 °C, representing a styrene-dicyclopentadiene-indene copolymer with a molecular weight of 600–800, manufactured by the group “Eurohem” companies.

For the second step were used the following solvents which are organic solvents: Solvent No 1 which is a product oil distillation, a mixture liquid aromatic and aliphatic hydrocarbons (not more than 50 % from each group), with a density of not more than 795 kg/m^3 (at 20 °C) and with a boiling point not higher than 165 °C, manufactured by CJSC "ARIKON"; Solvent No. 2 which is a direct distillation product the middle distillate oil fraction, with a boiling point in the range of 150-250 °C and density at 20 °C 780–850 kg/cm^3, manufactured by CJSC "ARIKON".

Also for the second step was used following carbon nanofiber (CNF) “Pyrograf III Carbon Nanofiber” which is one-dimensional filiform nanoscale graphite particles that do not have a pronounced cylindrical orientation of graphene layers, as well as an internal cavity manufactured by “Pyrograf Products”, USA. CNF “Pyrograf III Carbon Nanofiber” which is nanomodying additive.

The composition of the modified bitumen binder was developed based on the assessment of the influence of petroleum polymer resins on the following physical and mechanical properties of bitumen: needle penetration depth at 25 °C; needle penetration depth at 0 °C; softening temperature and adhesion.

The influence petroleum polymer resins on the structurally sensitive properties the bitumen binder was evaluated using a Physica MCR 101 CR-Rheometer (viscometer), in shear rate control mode, using a measuring system such as coaxial cylinders.

For a material that is in a structured liquid state, the rheological curve which is an S-shaped curve located inside the angle formed by tangents that pass through the origin, Fig. 1.

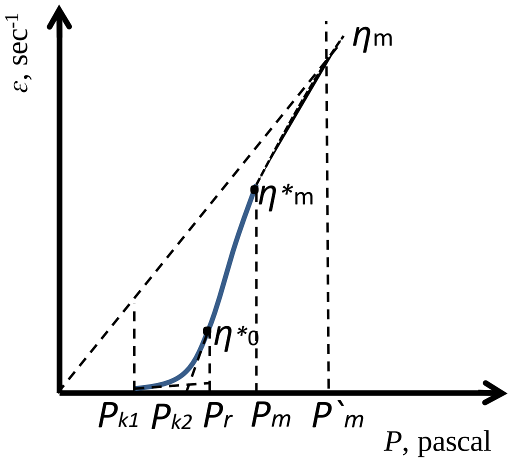

Figure 1. Rheological curve of a system with a conditionally elastic deformation zone.

Based on the rheological curve (Fig. 1) are determined by the rheological parameters elastic-plastic-viscous properties of disperse systems: η^*_0 which is the highest ultimate viscosity of the almost none destructed structure; η_m which is the lowest ultimate viscosity of the extremely destroyed structure; $P`_m$ which is a boundary shear stress corresponding to the ultimate destruction of the structure, η^*_m which is the smallest of the plastic (Bingham) viscosity; P_{k2} which is conditional yield strength corresponding to the ultimate dynamic shear stress; P_{k1} which is conditional yield strength corresponding to the ultimate static shear stress.

Optimization of the composition of the modified bitumen binder was carried out using specific quality criteria describing which is the influence of the percentage of petroleum polymer resin on each quality indicator. Based on the partial quality criteria were calculated a generalized criterions which are showing the degree of modification of the bituminous binder from the content of petroleum polymer resin.

Nano modified suspension was developed by introduced of carbon nanofiber to a solvent. The distribution of carbon nanofibers in the solvent was carried out using an ultrasonic disperser Sonics Vibra-Cell VCX 750. Sound vibrations which are the frequency level of 20 kHz, the dispersion power which is 750 W. The appearance samples dispersed media "solvent – carbon nanofibers" before and after ultrasonic dispersion is shown in Fig. 2.

a) **b)** **c)**

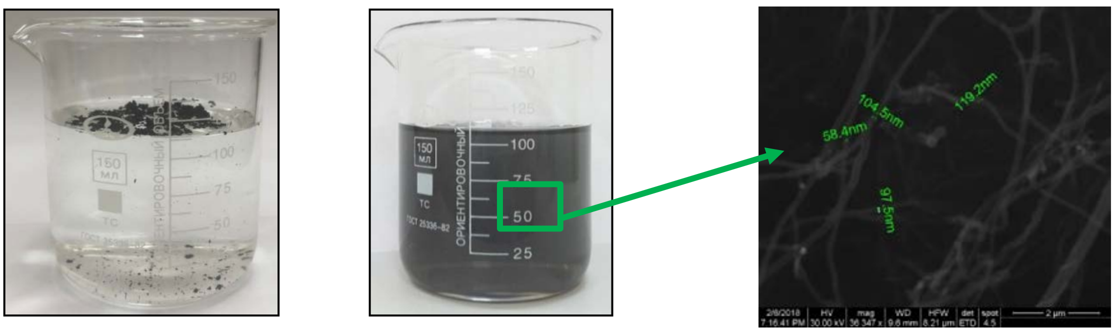

Figure 2. Appearance samples: a – before ultrasonic dispersion;
b – after ultrasonic dispersion; c) micrograph carbon nano modifier after ultrasonic dispersion.

In accordance with the preliminary experiment, it was found that the significant effect of nanofiber on the properties of the protective reducing material is in the range from 0.1 to 0.001 % by weight of the solvent.

The size carbon nanofibers were determined on a Zetatrac instrument using laser diffraction. Choice the specified carbon nanofibers which are modifier is justified by the following:

1) carbon nanofibers have a high affinity for organic solvents and bitumen binder (this is evidenced by the numerous positive results obtained by domestic and foreign researchers);

2) carbon nanofiber has a lower cost compared to single and multilayer nanotubes, respectively an average 25 and 8 times.

The preparation of the control composition of the protective rejuvenator in laboratory conditions was carried out with sequential multi-stage mixing materials in according with third step which is the above. Optimization of the control composition of the protective rejuvenator was carried out in following quality indicators: of drying time, homogeneity and adhesion. The optimal control composition of the rejuvenation material was selected based on the value of the developed generalized quality criterion including particular quality criteria that considered the values of the obtained properties.

The preparation of the nanomodified composition of the rejuvenation and protective material was carried out in accordance with the third step and the addition (which is the above) of a nanomodifier in accordance with the second step (that is, the preliminary introduction of carbon nanofibers into the solvent). Impact research carbon nanofibers on the properties of the protective rejuvenator was carried out in following quality indicators: of drying time, homogeneity and adhesion.

Impact research nano-modified protective and rejuvenator materials on the properties of asphalt concrete was carried out in following quality indicators compressive strength, crack resistance, internal friction coefficient, shear adhesion, and water resistance. The optimal nano-modified protective and rejuvenator materials were selected based on the value of the developed generalized quality criterion including particular quality criteria that considered the values of the obtained properties.

3. Results and Discussion

To select the effective one from the considered petroleum polymer resins, we evaluated their influence on the physic mechanical properties bitumen binders, Fig. 2–7 and their adhesion to the mineral stone (Table 1).

Establishing the influence petroleum polymer resins on the formation a structure was studied by indicators characterizing the greatest resistance to shear in two critical structural states: the highest ultimate viscosity of the almost none destructed structure the bitumen binder; the lowest ultimate viscosity of the extremely destroyed structure a bitumen binder. From the point of view rheology and physical chemistry bitumen binders are colloidal dispersed systems characterized by a sharp change in the structural and mechanical properties temperature. So it is advisable to study them in the temperature range corresponding to the manufacturing and application technology.

The results of the influence of different percentages petroleum polymer resins are presented in Fig. 3.

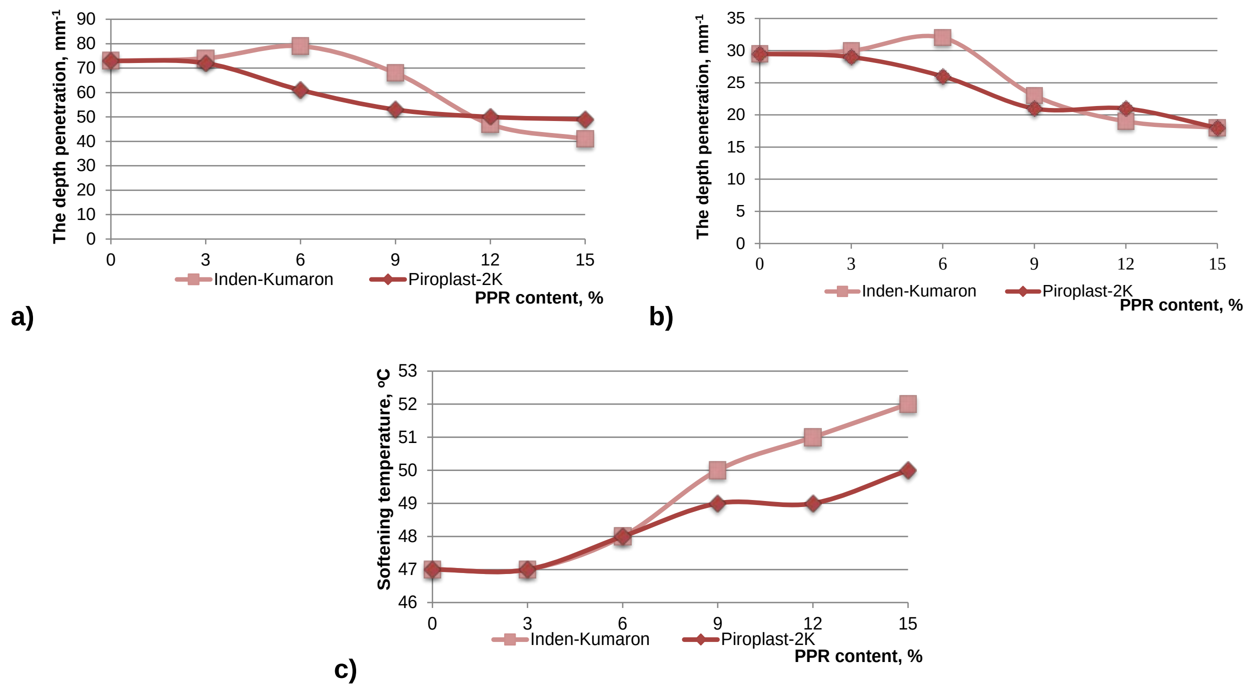

Figure 3. The influence content petroleum polymer resins on the physical and mechanical properties the bitumen binder: a) the depth penetration of the needle at 25 °C; b – the depth penetration of the needle at 0 °C; c – softening temperature.

Table 1. Effect from the content PPR on the adhesion bitumen with mineral stone.

Property	Content PPR, %					
	0	3	6	9	12	15
			Inden Kumaron			
Adhesion, point	2	3	4	4	4	4
			Piroplast-2K			
Adhesion, point	2	2	3	3	4	4

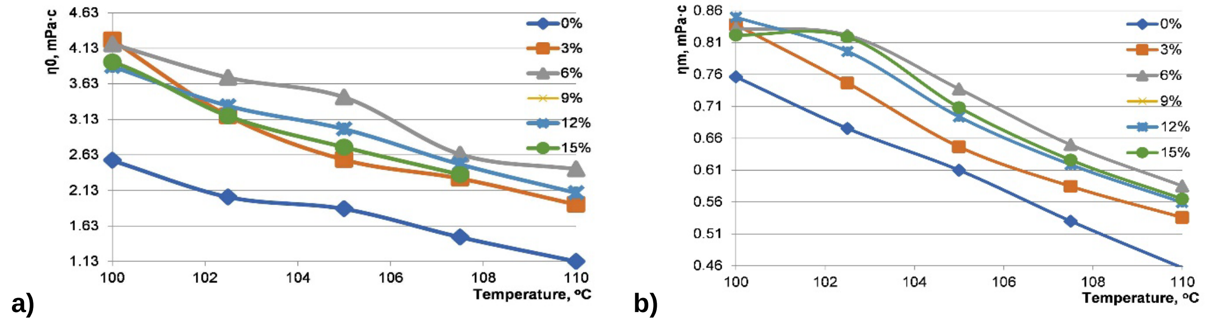

Figure 4. The influence content PPR Inden-Kumaron and temperature:
a – the highest ultimate viscosity of the almost none destructed structure the bitumen binder;
b – the lowest ultimate viscosity of the extremely destroyed structure a bitumen binder.

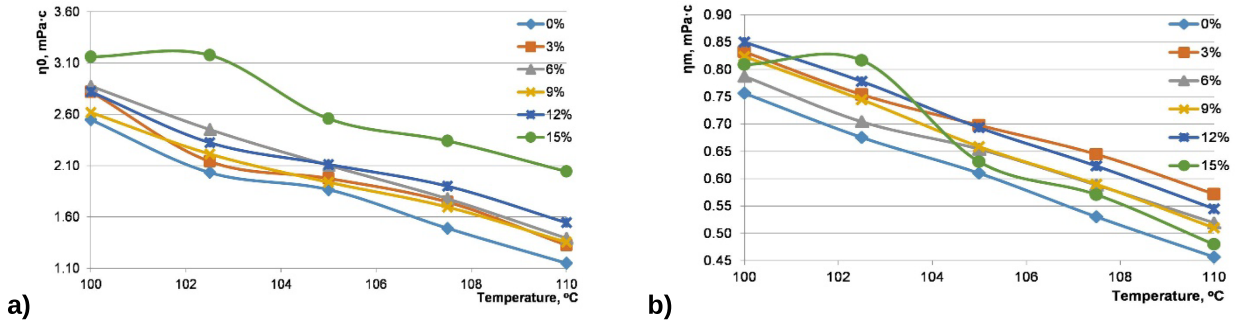

Figure 5. The influence content PPR Piroplast-2K and temperature:
a – the highest ultimate viscosity of the almost none destructed structure a bitumen binder;
b – the lowest ultimate viscosity of the extremely destroyed structure a bitumen binder.

The numerical value of the ability structured systems at various temperatures to resist shear is expressed by the conditional elastic modulus [18]:

$$E = \frac{\eta_0}{\eta_0 - \eta_m} \cdot P_r', \quad (1)$$

where η_0 which is the highest ultimate viscosity of the almost none destructed structure a bituminous binder; η_m which is the smallest ultimate viscosity extremely destroyed structure bituminous binder; P_r' which is boundary stress corresponding to the almost none destructed structure bitumen binder, corresponding to the beginning of the process destruction structure.

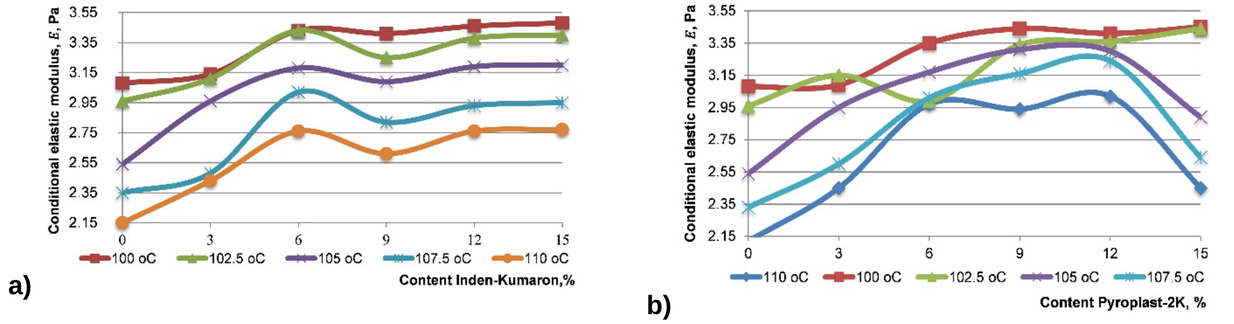

Figure 6. The influence content PPR on the conditional elastic modulus bitumen binder:
a – Inden-Kumaron; b – Pyroplast-2K.

The influence content petroleum polymer resins in the modification bitumen binder (Fig. 3–8) was evaluated according to the following developed particular criteria:

– I_{CiJ} which is the criterion characterizing the effect of the content oil-polymer resins on the depth penetration the needle at 0 and 25 °C, softening temperature and adhesion:

$$I_{C_i j} = \left(\frac{I_{j(PPR)} - I_{j(Bitumen)}}{I_{j(Bitumen)}} \right) \cdot \frac{1}{c_i} \cdot 100\%, \quad (2)$$

where $I_{j(PPR)}$ which is the numerical value the property indicator of bitumen with PPR; $I_{j(Bitumen)}$ which is the numerical value the property indicator of bitumen; C_i is the content PPR, % by weight.

– I_{CiE_T} which is the criterion characterizing the effect content of oil-polymer resins on the relative change in the conditional elastic modulus:

$$I_{C_i E_T} = \left(\frac{I_{E_T(PPR)} - I_{E_T(Bitumen)}}{I_{E_T(Bitumen)}} \right) \cdot \frac{1}{c_i} \cdot 100\%, \quad (3)$$

where $I_{E_T(PPR)}$ which is the numerical value the conditional elastic modulus the bitumen with PPR at a certain temperature; $I_{E_T(Bitumen)}$ which is the numerical value the indicator conditional elastic modulus the bitumen.

The presented particular criteria were also used to calculate the average values the particular criteria in the studied temperature range:

$$I_{C_i E} = \frac{\sum_1^n I_{C_i E_T}}{n}, \quad (4)$$

$$F_{C_i} = \frac{\sum_1^n I_{C_i j}}{n}, \quad (5)$$

where n which is the number of particular criteria.

The results calculation, particular criteria and given quality criteria are presented in Tables 2 and 3.

Table 2. Particular criteria characterizing the percentage contribution of a petroleum polymer resins to the modification the bitumen binder.

Private quality criteria	PPR content, %				
	3	6	9	12	15
			Inden-Kumaron		
$I_{Ci\ P25}$	0.46	1.37	–0.76	–2.97	–2.92
$I_{Ci\ P0}$	0.56	1.41	–2.45	–2.97	–2.60
$I_{Ci\ T\ softening}$	0.00	0.35	0.71	0.71	0.71
$I_{Ci\ Adhesion}$	16.67	16.67	11.11	8.33	6.67
$I_{Ci\ E}$	2.81	3.64	1.86	1.75	1.44
			Pyroplast 2K		
$I_{Ci\ P25}$	–0.46	–2.74	–3.04	–2.63	–2.19
$I_{Ci\ P0}$	–0.56	–1.98	–3.20	–2.40	–2.60
$I_{Ci\ T\ softening}$	0.00	0.35	0.47	0.35	0.43
$I_{Ci\ Adhesion}$	0.00	8.33	5.56	8.33	6.67
$I_{Ci\ E}$	3.34	3.46	2.87	2.26	0.95

Table 3. Average values of particular quality criteria.

Quality criteria	PPR content, %				
	3	6	9	12	15
			Inden-Kumaron		
F_{ci}	4.1	5.0	2.1	1.0	0.7
			Pyroplast 2K		
F_{ci}	0.5	1.5	0.5	1.2	0.7

An analysis the results (Table 3) shows that the greatest modifying effect, estimated by the value he criterion, when introduced into the bitumen binder the considered petroleum polymer resins is observed at their content of 6 %. The indicated content of the PPR was used for further research and development for basic (control) composition.

At the second step the development composition of the nano-modified rejuvenator and protective material. At this step, it is necessary to choose a solvent compatible with the organic bitumen binder, as well as allowing for maximum dispersion the carbon nanofiber and the stability its suspension.

Dispersion of carbon nanofibers were carried out in two solvents. In this case, suspensions were obtained with two concentrations carbon nanofiber C1 = 0.001 % and C2 = 0.01 %. The dispersion quality was estimated by the value reduced diameter of the dispersed phase (carbon nanofiber) in the suspension (Fig. 7).

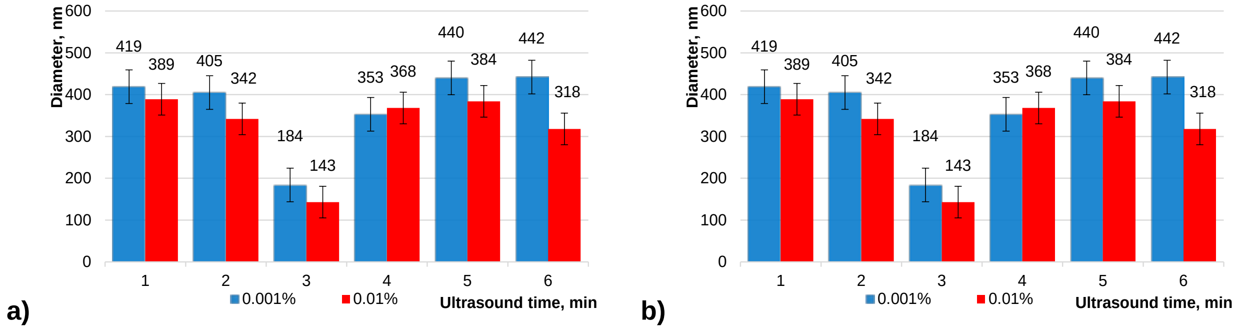

Figure 7. The influence of duration ultrasonic dispersion on the average reduced diameter the carbon nanofibers in suspension: a – Solvent No 1; b – Solvent No 2.

The results obtained (Fig. 7) show that the dependence average reduced diameter the carbon nanofiber in suspension on the duration dispersion is extreme. The smallest value the average diameter of carbon nanofiber in suspension for Solvent No. 1 is observed after 3 minutes dispersion and for Solvent No. 2–4 minutes the dispersion. The average reduced diameter the carbon nanofiber in suspension for Solvent No. 1 is 143–184 nm, and for Solvent No. 2 it is 108–139 nm (depending on the concentration of carbon nanofiber). However, suspensions based on Solvent No. 2 are not stable and precipitation occurs after 7 days of storage. In this regard, in further work, Solvent No. 1 was used as the main medium for the preparation of the suspension.

For RM, ceteris paribus, important quality indicators are: the uniformity the material, which must be maintained for a given period; drying time and adhesion. It is natural that the solvent content will have a significant effect on these properties. Establishing the optimal ratio, the components of the RM and evaluating their compatibility was carried out for 3 formulations (Table 4). The introduction of a lower solvent content into the bitumen binder led to a significant increase in the drying time which was more than 180 minutes, and the introduction of a larger amount of solvent led to an unsatisfactory adhesive adhesion and uniformity the RM.

Table 4. Composition and properties of RM.

Name of components	No. composition		
	1	2	3
	Content of components, %		
Modified binder: -Bitumen 90/130 – 100 % -PPR Inden-Kumaron – 6 %	45	55	65
Solvent No. 1	55	45	35

Table 5. Technological and operational properties of RM.

Property	Requirements of Russian industry road guidance document (IRGD) 218.3.073-2016	No. composition		
		1	2	3
		Actual results		
Drying time, min	on more 180	55	60	95
Homogeneity after 7 days	uniformly, no clumps or clots			
Adhesion, point	no less 4	3	4	4

Results presented in Table 4 show that the composition No. 1 does not meet the requirements of IRGD 218.3.073-2016 for adhesion. For this indicator, only compositions No. 2 and 3 can be used. Moreover, according to the “Drying Time” indicator, all the studied compositions meet the requirements: composition No. 3 (95 min.) Has a maximum value, and composition No. 1 has a minimum value (55 min). By homogeneity, all compositions also comply with the requirements the normative and technical document. In this regard, the choice of the composition RM can be carried out by a generalized criterion of the form:

$$F_m = \sqrt[3]{\frac{60}{I_t} I_{Adh} I_{Un}}, \tag{6}$$

where I_t is the indicator "Drying time" (60 – normalization coefficient); I_{Adh} is indicator “Adhesion” (when fulfilling the requirements normative-technical document on adhesion I_{adh} = 1; if the requirement is not fulfilled, I_{Adh} = 0); I_{Un} is indicator “Uniformity” (in the absence of clots and lumps I_{Un} = 1; in the presence of clots and lumps I_{Un} = 0).

The values generalized criterion F_m for composition No. 1 F_m = 0, for composition No. 2 F_m = 1, and for composition No. 3 F_m = 0.86.

Thus, according to the specified quality indicators, the optimal composition is No. 2, containing the modified bitumen binder – 55 %, Solvent No. 1 – 45 %.

The positive effect of nanoscale modifiers on the properties bitumen materials is widely known, see for example [19, 20]. The introduction nanomodifier in the RM will further structure the maltene component the modified bitumen binder, which will increase its cohesive and adhesive strength.

At the third step development of the nanomodified composition the protective rejuvenation material, the optimal content of the nanomodifier which is carbon nanofiber was selected, Table 5.

Table 5. The composition and properties of nanomodified rejuvenating materials.

Name of components	No. composition			
	Without CNFc (control)	1	2	3
	Content of components, %			
Modified binder:				
-Bitumen 90/130 – 100 %	55			
-PPR Inden-Kumaron – 6 %				
Solvent No. 1	45			
Carbon nanofiber	–	0.001	0.01	0.1
Property	Actual results			
Drying time, min	60	50	43	42
Homogeneity after 7 days	uniformly, no clumps or clots			
Homogeneity after 21 days	sediment	uniformly		
Adhesion, point	4	5	5	5

The results presented in Table 5 show that the introduction of carbon nanofiber in the studied range can improve adhesion by 25 % and shorten the drying time by 16–30 %.

For study the influence of the developed rejuvenator materials on the asphalt concrete quality indicators was selected and tested corresponding in grain composition, to the type mastic asphalt concrete SMA-15. The design of the asphalt mix was carried out in accordance with the requirements of Russian state standard 31015-2002. For a comparative analysis the results the development RM, a comparison was made with existing industrial analogues the domestic (Brit-RM) and foreign (Surtreat) production, the consumption of which corresponded to the recommended ones from the manufacturer – 1.0 and 0.35 l/m^2, respectively. The consumption of the developed RM was 0.35 l/m^2.

The choice of the optimal composition the RM was carried out according to the value of the generalized quality criterion, calculated by the formula:

$$F_k = \sqrt[5]{K_{fm}} = \sqrt[5]{k_{R20} \cdot k_{Rp} \cdot k_{tg} \cdot k_C \cdot k_W}, \tag{7}$$

where k_{R20} is the coefficient taking into account the relative change in compressive strength; k_{Rp} is the coefficient taking into account the relative change in crack resistance during compression; k_{tg} is the coefficient taking into account the relative change in the coefficient of internal friction; k_C is the coefficient taking into account the relative change in adhesion during shear; k_W is the coefficient taking into account the relative change in water resistance during prolonged water saturation.

Table 6. The influence RM on the properties of asphalt concrete.

Property	Actual results					
	Without RM	Asphalt samples processed by RM				
		Surtreat (USA)	Brit-RM (Russia)	No.1	No.2	No.3
Compressive strength, MPa, at a temperature of 20 °C	3.9	4.3	4.2	4.4	4.4	4.4
Crack resistance, MPa, at a temperature of 0 °C	3.1	3.9	4.4	4.2	4.5	4.7
Internal friction coefficient	0.94	0.94	0.94	0.94	0.94	0.94
Shear adhesion at a temperature of 50 °C, MPa	4.24	3.12	3.11	4.20	4.30	4.50
Water resistance with prolonged water saturation	0.89	0.95	0.93	0.98	0.98	0.99

The optimal composition corresponds to the maximum value of the generalized quality criterion. The results of experimental studies the properties of asphalt concrete samples treated with developed RM with different contents the nanofiber and samples treated with analogues are presented in Table 7.

The results calculation of the generalized quality criterion is presented in Table 7.

Table 7. Values of the generalized quality criterion.

Property	Actual results					
	Without RM	With RM				
		Surtreat (USA)	Brit-RM (Russia)	No. 1	No. 2	No. 3
Compressive strength, MPa, at a temperature of 20 °C	1.00	1.10	1.08	1.13	1.13	1.13
Crack resistance, MPa, at a temperature of 0 °C	1.00	1.23	1.39	1.33	1.43	1.49
Internal friction coefficient	1.00	1.00	1.00	1.00	1.00	1.00
Shear adhesion at a temperature of 50 C, MPa	1.00	0.74	0.73	0.99	1.01	1.06
Water resistance with prolonged water saturation	1.00	1.07	1.04	1.10	1.10	1.11
Generalized quality criteria	1.00	1.01	1.00	1.10	1.12	1.15

From the data of Table 7, it follows that the introduction carbon nanofiber in an amount of 0.001 ... 0.1 % by weight RM provides an increase in the effectiveness of the impregnating composition on the properties asphalt concrete. Nanomodified rejuvenator and protective material the composition No. 3 is characterized by the maximum value the generalized quality criterion. At the same time, its use allows to increase performance indicators: compressive strength by 12.8 %; crack resistance by 49 %; shear adhesion by 6.1 % and water resistance by 11 %.

It was also established that the existing industrial analogues RM of Russian and foreign production in terms indicators did not demonstrate a significant effect on the properties the asphalt concrete, which makes research aimed at developing effective compositions of RM relevant and promising.

4. Conclusion

1. It was proposed a method for calculating the conditional elastic modulus of structured fluids using the results rheological tests.

2. It was proposed a generalized criterion for calculating the degree of modification bitumen binder with petroleum polymer resins considering the content contribution modifier. It was found that the optimal content of petroleum polymer resin is 6 %.

3. It has been established a solvent which provides disperses carbon nanofiber to a diameter of 143–184 nm and which provides a suspension stability of up to 7 days.

4. It was established the possibility of using one of the by-products in the petrochemical industry which is petroleum polymer resin which is a modifier in rejuvenator and protective materials. This will help to solve the acute problem of waste disposal of chemical and petrochemical production. However, it should be noted that the compositions of RM containing the specified modifier which is petroleum polymer resin, were characterized by low adhesive ability.

The introduction carbon nanofiber in the amount of 0.001...0.1 % by weight of the rejuvenator and protective material allows us to further structure the maltene component the modified bitumen binder, which enhances the modifying effect to increase the performance characteristics of asphalt concrete: compressive strength by 13 %; crack resistance by 49 %; shear adhesion by 6.1 % and water resistance by 11 %.

5. Acknowledgment.

Financial support for this work was obtained from Russian Science Foundation contract numbers: 21-79-00191, https://rscf.ru/en/project/21-79-00191/.

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