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Nanosized carbon modifier used to control plastic deformations of asphalt concrete

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Abstract. Aspects related to plastic track, the formation of which directly depends on the properties of the binder in the composition of asphalt concrete, are considered in this article. The effect of primary carbon nanomaterials on the quality of polymer and bitumen binder in comparison with the traditional binder including cross-linking agent is evaluated. The influence of binders on the resistance to the track formation of type B asphalt concrete is studied. To quantify the service life of surfacing, a calculation method based on the criteria for the resistance of surfacing material to plastic deformations is used.

1. Introduction

Today one of the most topical operational and transport issues is the increase of both shear and tracking strength of asphalt concrete in the road and airfield pavement. Asphalt concrete surfacing of transport facilities cannot be either crack resistant or shear and track stable. This is due to the structural sensitivity of asphalt concrete to the external aggressive environmental factors, which, against the background of ongoing degradation processes caused by the mechanical influences of the intensive transport flow leads to changes of its binding part, and as a consequence, changes of the plasticity of asphalt concrete. This, in turn, leads to a disruption in the continuity of the structure of asphalt concrete surfacing, i.e. cracking; besides, it leads to the loss of deformation stability to shear, rush, wheel tracking, etc.

A track on the surface of asphalt concrete surfacing can be formed under the influence of transport loads for several reasons: shearing irreversible deformation of the upper and lower layers of the surfacing; irreversible deformation of underlying layers of the foundation and soil of the subgrade; undercompaction and uneven wear rate of surfacing [1].

According to the foreign sources [2, 3], there are 3 types of the process of track formation: abrasive, plastic and tracking throughout the thickness. In case where the overall strength of the pavement does not correspond to the actual loads affecting the road, the track is formed over the entire thickness. If the overall strength of the pavement is met, the problem of plastic deformation on the surface occurs. There is also a case when the track formation is caused by an abrasive or wear-out track.

To eliminate the plastic track, both Russian and foreign researchers [3, 4] recommend using multi-ribbed dense asphaltic concrete, as well as other types of asphalt concrete, which have high shear stability and the ability to resist the accumulation of residual deformations.



Shift stability of asphalt concrete surfacing is determined by the rheology of bituminous binders and their heat resistance. One of the available and widely used methods aimed at the improvement of shear stability of a road composite is the modification of binders with various additives, and primarily polymeric ones [5-8].

The increased resistance of surfacing on polymer bitumen binders (PBB) to plastic deformations and tracking resulted in a wide use of this type of binder in the road building industries of many European countries [9-11].

In the Russian Federation, the segment of the bitumen market is relatively young, however, dynamically developing. The transport strategy of the Russian Federation is in the process of development and is aimed to toughen the requirements set for raw and composite materials, construction, as well as the implementation of life cycle contracts for road facilities by decree No.1087 of 28 November 2013 of the Russian Federation Government.

The factors mentioned above stimulate the science to develop and expand the ways aimed at improving the quality of organic binders. A promising direction in this area is the use of nanomodification technology of binders with primary carbon nanomaterials (PCN). Application of such technology makes it possible to improve the effectiveness of macromodification [12-13]. Besides, it helps inhibit their deficiencies [14-18].

2. Materials and methods

The effect of primary carbon nanomaterials on the quality of polymer bitumen binder was evaluated and the influence of nanomodified binder on the tracking stability of asphalt of type B was studied. The research objects used in this work were the following: oil bitumen BND 90/130 produced by OOO Moskovsky Refinery; polymer of thermoplastic elastomers class - DST-30R-01 produced by AO Voronezhskintezkauchuk; organic plasticizer - industrial oil of grade I-40; base material of single-walled carbon nanotubes (SWCNT) synthesized in the Russian Academy of Sciences, Chernogolovka obtained by thermal evaporation of graphite in the presence of Ni-Cr catalyst in an electric arc (Arc SWCNT). An important aspect when choosing a plasticizing medium in favor of industrial oil is possibility to evaluate the uniform distribution of CNM in its volume, compatibility with the studied component composition, as well as high technological efficiency [17].

3. Experimental part

Basing on the studies carried out earlier [17-18], where optimal and efficient modes of dispersion and uniform distribution of SWCNT in the volume of the modified binder matrix were selected, based on bitumen BND 60/90, and an optimal concentration range was established in which the effectiveness of CNM introduction into the composition of the PBB, the concentration of SWCNT equal to $2 \cdot 10^{-3}\%$ was adopted.

Varying this component composition, the samples of PBB-60 were prepared. An industrial binder with a polymer content of 4.5% was adopted as a reference sample. In order to simplify the model under study, it was decided to take with two components: polymer and nanomodifier. The content of the plasticizer has been previously selected, provided that its properties meet the requirements of GOST 52056-2003 with a polymer content of 4.5, i.e. similar to the industrial binder. Preparation of PBB samples was carried out according to the standard technology. The mixing process was performed with a paddle mixer followed by maturation in a drying cabinet.

The developed laboratory PBB-60 (No.2-4) samples and industrial reference sample (No.1) are presented in Table 1. Their physical and mechanical parameters are presented in Table 2.

Table 1. Composition of studied binder samples

Name of component	Samples of polymer bituminous binders			
	1	2	3	4
SWCNT, %	-	-	0.002	0.002
DST-30P-01, %	4.5	4.5	2.8	3.2
Plasticizer, %	-	2.0	2.0	2.0
Bitumen, %	100*	100	100	100

100 * - prepared binder, including its plasticizing and cross-linking components

As it can be seen from Table 2, composition No. 2, containing polymer similar to the industrial composition (4.5%) is much worse in relation to heat resistance, elasticity and adhesion, which suggests the use of cross-linking agents in the composition of modified binder. When adding SWCNT nanomodifier to PBB (No. 4), according to the developed technology [17] and with the preliminary distribution in the precursor medium, before adding it to the binder, the characteristics of studied binders are improved. The achievement, and in some cases, the prevalence of given properties (heat resistance - 10%, 5% of elasticity at 25 ° C) was found out in PBB composition No. 4 with a polymer content of 3.2%, which is 29% below the production value.

Table 2. Indicators of properties of studied binders

Name of indicators	GOST 52056-2003, PBB 60	Initial bitumen 90/130	Binder samples PBB 60, composition No.			
			1	2	3	4
Penetration depth of needle is 0.1 mm, not less than at 25 ⁰ C	60	94	65	67	68	66
at 0 ⁰ C	32	44	35	33	34	35
Extensibility, cm, not less than at 25 ⁰ C	25	72	68	65	56	72
at 0 ⁰ C	11	20	34	16	20	41
Softening temperature, ring-and-ball method, °C not less than	54	47	68	65	61	75
Temperature of brittleness according to Fraas, not higher than T _{xp}	-20	-19	-23	-20	-23	-24
Change in softening temperature after warming up, °C, not higher than	5	5	3	4	1	1
Adhesion, points to granite		4	4	3		5
quartzite sandstone	-	3	4	3		5
limestone		4	5	4		5
Homogeneity	homogenous	-		homogenous		
Elasticity not less than, % at 25 ⁰ C	80	-	93	89	90	98
at 0 ⁰ C	70	-	75	74	87	92

It is commonly believed that the use of plasticizer in the composition of PBB has a detrimental effect on its adhesion properties. Therefore, it was of an interest to study the change in the adhesion

properties of such PBB. Adhesion bond was evaluated on a five-point scale by means of stone materials boiling different in basicity (Table 2). As it can be seen, the industrial binder (composition No. 1) corresponds to the requirements, but it should be noted that these values are borderline. The introduction of nanoscale objects (composition No. 4) makes it possible to provide a stock of adhesive bond of the binder with all mineral materials regardless of basicity.

The next step of the study was the evaluation of the ability of modified binder combined with the mineral skeleton of asphalt concrete to function effectively in the surfacing of roads and resist negative external factors.

The modern test method, simulating actual conditions of the roadway under the influence of transport load implies the determination of stability of asphalt concrete to the formation of track on the laboratory equipment InfraTest 20-4000. To this end, special samples of asphalt concrete of type B with the same binder content were prepared in the sectorial compactor (roller compactor) of InfraTest 20-4030 according to the standard procedure EC EN 12697-22. The binders PBB (No. 1 – No. 2) were used as binders. The idea of the method is to study the track on an asphalt concrete slab formed by the repeated movement of a wheel, imitating a car with the given vertical load. The samples were tested in an aqueous medium at a temperature of 60 ° C. To evaluate the results obtained, the measurement of a track depth corresponding to 20,000 wheel passes was made.

Numerous studies [1-3, 19] proved that this method allows predicting the behavior of asphalt concrete in real operating conditions and evaluating material properties that are difficult to assess when tested with a single breaking load. Thus, it becomes possible to establish the efficiency from the modification of asphalt concrete, which will be characterized by the greatest resistance to the formation of track.

The results of the study of the track resistance of asphalt concrete samples to the appearance of plastic deformations are shown in Fig. 1. The numbers of the diagrams in the figure correspond to the numbers of the compositions in Table. 2.

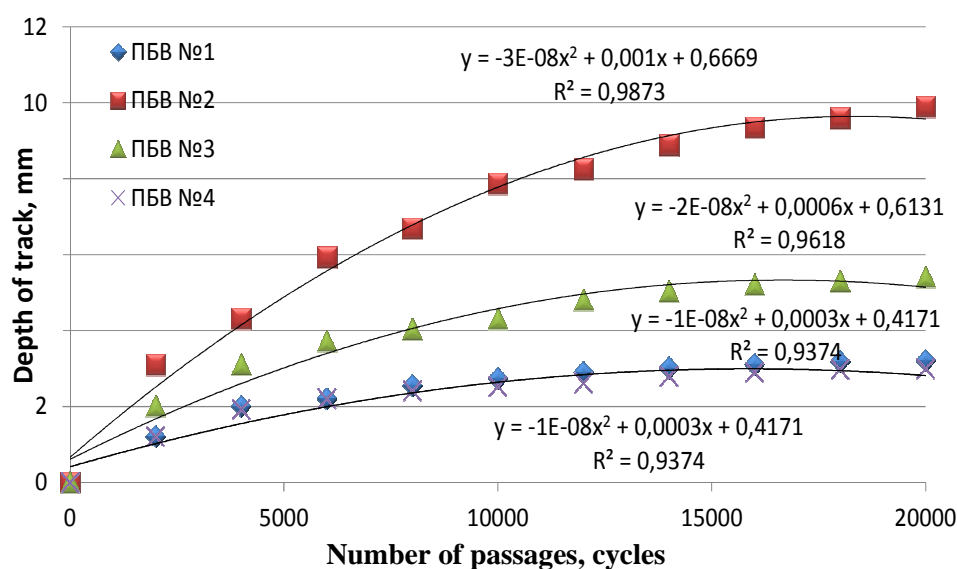


Figure 1. Steadiness of asphalt concrete of type B on PBB of different composition

The analysis of the obtained results showed that the changes in the properties of all asphalt concrete samples prepared on various binders are polynomial in nature with the reliability of at least 94%. The sample of asphalt concrete of type B prepared on the basis of the laboratory composition (No. 2), despite a significant polymer content of 4.5%, showed the worst result; the track depth after 20,000 wheel passes was 9.89 mm, while in the samples of asphalt concrete on the basis of the production

sample PBW (No. 1), containing cross-linking agents and the nanomodified binder (No. 4), an insignificant track of 3.21 and 3 mm was observed, respectively.

Based on the obtained results on the stability of asphalt concretes from the tracking to plastic deformations, it can be assumed that the use of nanomodified asphalt concretes in the construction of road surfacing will extend the defect-free service life of the road.

To carry out qualitative evaluation of the service life of surfacing, the calculation method described in the Scope of Recommendations for the Selection of Asphalt Concrete Mixtures 02191.2.051-2012 was used. Service life is calculated by the criteria of resistance to plastic deformation. The following formula is used for the above-mentioned calculations:

$$T_{plast} = (K_{cond} \cdot H_{cr}) / (H_1 \cdot H_{calc} \cdot T_{60})$$

where, K_{cond} is the coefficient of traffic conditions; for space-limited conditions (bridges, overpasses, tunnels). 1.0 is taken; in other cases it would be 1.3;

H_{cr} is critical deformation (permissible depth of track), m in accordance with GOST R 50597-93;

H_1 is the value of plastic deformation (depth of track) after one cycle of the impact of the wheel load at a temperature of 60 °C;

H_{calc} is the traffic density per lane, vph. It is calculated basing on the results of observations for a specific part or section of the road. In case such observations do not take place, the traffic density is calculated on the basis of design and construction specifications 34.13330.2012;

T_{60} is the number of hours per year with the surfacing temperature amounting to 60 °C and above, h/year. It is calculated using the weather station data in a specific region.

For this work, the coefficients presented in Table 3 were taken.

Table 3. Coefficients for calculating the service life of surfacing

Name of coefficient	Compositions of polymer concrete mixes on binders			
	No. 1	No. 2	No. 3	No. 4
K_{cond} ,	1.3	1.3	1.3	1.3
H_{cr} , m	0.05	0.05	0.05	0.05
H_1 , m	$28 \cdot 10^{-8}$	$7 \cdot 10^{-8}$	$8 \cdot 10^{-8}$	
H_{calc}^* , vph	250	250	250	250
T_{60} , h/year	230	230	230	230

Note: H_{calc}^* is the value taken for the road of category III with the type of asphalt concrete of type B, grade II

Calculation results of estimated service life (for plastic deformations) of defect-free surfacing of roads, applying the solutions under study, are shown in Fig. 2.

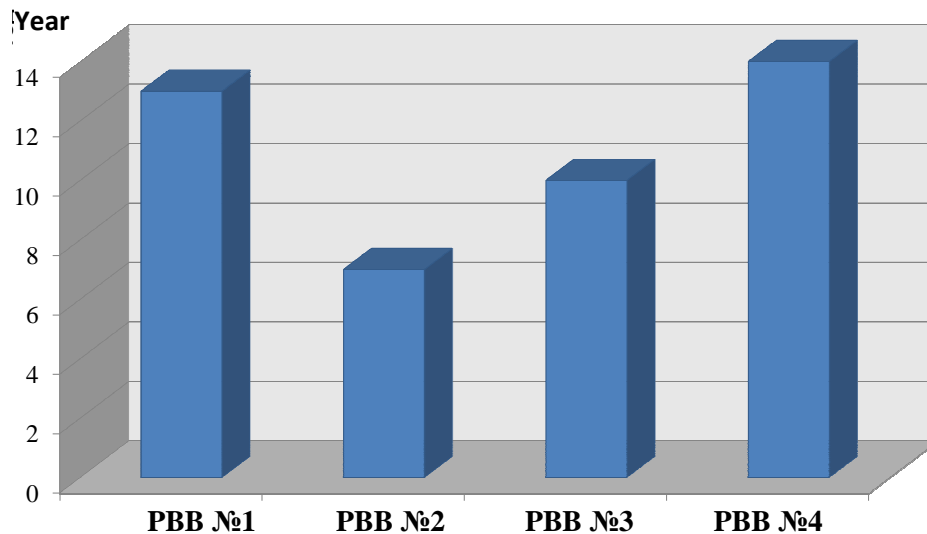


Fig. 2. Dependence of the change in the estimated service life of surfacing on the used solution

The presented results show that the lowest value (7 years) of the estimated service life corresponds to the sample of asphalt concrete based on the laboratory composition of PBB No. 2 with a polymer content of 4.5%. The best results are typical for the samples of asphalt concrete based on production sample of PBB No. 1 (13 years), which contains cross-linking agents and is based on nanomodified PBW No. 4 (14 years).

4. Summary

As a rule, the reason of track (or washboard) formation is complex and it is possible to identify only the predominant factor in the process of formation of the track. To solve this problem, it is necessary to take into account all the factors and apply complex measures to prevent the formation of tracks. These include the improvement of design methods for asphalt and road construction in general, smaller number of vehicles with high axial loads on the roads, and limitation of studded snow tiers.

In this article, the compliance of the overall strength of pavement was considered (the main problem was the result of plastic deformation on surfacing). The obtained results make it possible to conclude that the composition of polymer bitumen binders lacks one modifying component, which is a polymer. To ensure the resistance to the formation of tracks from plastic deformations, it is necessary to introduce additional components among which there are the cross-linking agents and primary nanomaterials. The use of these components makes it possible to improve complex properties of the binder, which helped to increase the design time (according to the criteria of plastic deformations) of the road surfacing up to 75%. Primary nanomodifier (SWCNT) results in the possibility to reduce the content of expensive polymer by 29%.

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