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ПРИМЕНЕНИЕ НАНОМОДИФИКАТОРОВ ДЛЯ ПОВЫШЕНИЯ КАЧЕСТВА ДОРОЖНЫХ БИТУМОВ

Г.В. Проваторова

Галина Владимировна Проваторова

Кафедра «Автомобильные дороги», Владимирский государственный университет, ул. Горького, 87, Владимир, Российская Федерация, 600000
E-mail: asf.inst@yandex.ru

Вопросы повышения качества дорожных битумов и влияние свойств вяжущего на эксплуатационные показатели асфальтобетона являются в последние годы весьма актуальными. Исследования, проводимые на кафедре автомобильных дорог Владимирского госуниверситета, показали, что даже наиболее эффективные модифицирующие добавки, применяемые в дорожном строительстве, не всегда дают требуемый результат, или результат достигается введением значительного количества модификатора, что дает заметное удорожание вяжущего и асфальтобетона на его основе. Целью данной работы является выбор нового (ранее не использовавшегося в области) модификатора для битумов, применяемого в дорожных организациях Владимирской области, и исследование его свойств. По результатам эксперимента была разработана методика проведения опытных испытаний, определены свойства полученного модифицированного вяжущего и выполнено сравнение со свойствами исходных образцов и подбор состава добавок, формование и испытание образцов на полученном модифицированном вяжущем. Полученные результаты позволили сделать вывод о том, что примененный модификатор дает лучшие показатели, нежели ранее применяемые модификаторы.

Ключевые слова: дорожный битум, модификатор, наномодификатор, углеродные нанотрубки, колейность, трещиностойкость

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NANOMODIFIERS IN PRODUCING HIGHER QUALITY PAVING ASPHALT

G.V. Provatorova

Galina V. Provatorova

Department of Automobile Roads, Vladimir State University, Gorkogo st., 87, Vladimir, 600000, Russia
E-mail: *asf.inst@yandex.ru*

Recently it has become quite important to improve the quality of paving asphalt and study the influence of the properties of the binder on the asphalt concrete performance. Research conducted at the Department of Highways of Vladimir State University has shown that even the most effective modifying additives used in road construction do not always give the required result, or the result is achieved by introducing a significant amount of modifier, which gives a noticeable increase in the cost of binder and asphalt concrete that use it.
The purpose of this work is to select a new (previously not used in the Vladimir region) modifier for bitumen used in road construction companies in the Vladimir region, and study its properties. The results of experiment were used to develop the procedure of experimental tests, determine the properties of obtained modified binder, compare with the properties of original samples, select additives composition, mold and test samples on the obtained modified binder. The results allowed us to conclude that the applied modifier gives better performance than the previously used modifiers.

Key words: paving asphalt, modifier, nanomodifier, carbon nanotubes, rutting, crack resistance, asphalt concrete

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INTRODUCTION

Recently it has become quite important to improve the quality of paving asphalt and study the influence of the properties of the binder on the asphalt concrete performance. The problem is important mostly due to changes in the traffic composition. Significant increase in traffic and increase in axle loads of vehicles on the roads has led to the fact that asphalt concrete does not guarantee the required durability of road pavement. The durability of asphalt pavements is directly related to the quality of the materials used, primarily bitumen. Bitumen is most susceptible to change under the influence of transport loads and weather conditions. At the same time, bitumen largely determines the condition of the road surface. Bitumen behavior can be changed by modifying it with additives. The bitumen modifier can lead to a road coating resistant to cracking at low temperatures and fatigue at high temperatures. It also leads to rut resistance.

An important issue in selecting a modifier is the increased coating cost, as well as the cost of additional equipment, stability of the modified binder during storage and transportation, etc.

The purpose of this work is to develop a nano-modifier for bitumens used in road organizations in the Vladimir region, and to study its properties.

Recently, there has been a tremendous breakthrough worldwide in the production, study, and use of nanomaterials. Nanomaterials can act as modifiers of chemical reactions, technological and structural properties of materials they are added to [1].

Nanotechnological approaches lead to an increase in the competitiveness of Russian products, solving important problems of our time – energy saving and reducing the technogenic pressure of the building materials industry on the environment [2]. Modern trends in the development of nanodisperse modifiers cause a large and stable growth of other areas, including road material science [3].

Introduction of nanomodifying additives gives consumers the opportunity to increase strength and shear characteristics of road surfaces at elevated temperatures and improve the performance of road surfaces under traffic load with minor changes in the method of asphalt-concrete preparation.

Among carbon nanomaterials (CNMs), a special place belongs to carbon nanotubes (CNTs), which are 1–50 nm wide, several micrometers long, and form a new class of quasi-dimensional nanobjects. CNTs have several unique properties due to the ordered structure of their nanofragments. CNT-based materials can be successfully used as structural modifiers of construction materials [4]. The introduction of carbon nanotubes [5-8] into liquid bitumen significantly increases the durability and elasticity of the resulting asphalt coating.

It is important to note that due to the significant increase in the compressive strength index at +50°C, CNT in asphalt concrete mix can minimize the rutting of the road surface and improve its performance in summer, while maintaining the plasticity and necessary characteristics in winter.

Carbon nanotubes are molecular compounds that are long cylindrical structures, one to several tens of nanometers in diameter and one to several micrometers in length. CNTs can consist of one or more layers, each of which represents a hexagonal mesh of graphite (graphene), embedded into each other or rolled up into a tube. The grid is based on hexagons with carbon atoms in the corners. In all cases, the distance between the layers is 0.34 nm, as in graphite. The upper ends of the tubes are often closed with hemispherical lids, each layer composed of hexagons and pentagons. Carbon nanotubes are formed by thermal sputtering of graphite electrode in arc discharge plasma burning in helium atmosphere [9-11, 14, 15].

EXPERIMENT

The purpose of investigation is, firstly, to determine an optimal amount of additive introduced into bitumen and study properties of obtained binder, secondly, to improve main indicators of asphalt concrete mix based on the modification without a significant increase in production cost, thirdly, to increase asphalt concrete mix service life, which in its turn will reduce road maintenance costs.

The main objective is to analyze the effectiveness of the modification effect on the change in bitumen characteristics and, consequently, the effect on the strength properties of asphalt concrete.

Carbon nanotubes were used as a modifier for asphalt mixtures in the first phase of work.

The study was conducted with BND 70/100, which is the most widely used bitumen in the Vladimir region at this time. The technology for the preparation of modified bitumen includes the following processes:

1) Loading the initial bitumen preheated to a given temperature (160–165 °C), in a laboratory mixer.

2) Injection of a pre-dosed number of nanotubes into heated bitumen.

3) Thorough mixing of the binder with the modifier in the mixing unit, simultaneously heating it until a homogeneous state is reached within 2 hours.

The binder study includes:

- testing of the initial petroleum road bitumen of a given grade (Table 1);
- testing of modified petroleum road bitumen prepared in a lab (Fig. 1);
- subsequent analysis of the obtained data (Table 2).

As the results of research show, modifying bitumen by introducing inorganic binders, such as carbon nanotubes, creates a strong link between the binder and the stone material, increases the bitumen softening temperature, preventing ruts on the asphalt concrete pavement. It also becomes possible to increase the transportation distance of asphalt-concrete mixtures and extend the season of road works because it becomes possible to compact asphalt-concrete mixtures at a lower temperature.

During the experiment it was found that adding the modifier into the bituminous binder decreased Needle penetration depth at 25 °C and increased Softening point along the circle and ball and Dynamic viscosity at 60 °C. It should also be noted that cohesion and adhesion to mineral materials and resistance to oxidation and aging increases. The results are shown in Table 2.

***Table 1*. Test results of BND 70/100 grade bitumen**

No. of item	Indicator name, unit of measurement	Test method	GOST normal values	Real value
1	Needle penetration depth at 25 °C, 0.1 mm	GOST 33136	71–100	75
2	Softening point along the ring and ball, °C	GOST 33142	at least 47	57.0
3	Stretchability at 0 °C, cm: - at 1 cm/min - at 5 cm/min	GOST 33138	at least 3.7	 3.91 3.80
4	Maximum tensile force at 0 °C, N: - at 1 cm/min - at 5 cm/min	GOST 33138		 77.1 142.6
5	Brittle temperature, °C	GOST 33143	at most -18	-20
6	Flash point, °C	GOST 33141	at least 230	230

***Table 2*. Test results of bitumen grade BND 70/100+UN T**

No. of item	Indicator name, unit of measurement	Test method	GOST normal values	Real value
1	Needle penetration depth at 25 °C, 0.1 mm	GOST 33136	71–100	71
2	Softening point along the ring and ball, °C	GOST 33142	at least 47	54.1
3	Stretchability at 0 °C, cm: - at 1 cm/min - at 5 cm/min	GOST 33138	at least 3.7	 4.20 3.88
4	Maximum tensile force at 0 °C, N: - at 1 cm/min - at 5 cm/min	GOST 33138		 77.9 161.3
5	Brittle temperature, °C	GOST 33143	at most -18	-22
6	Flash point, °C	GOST 33141	at least 230	230

The next step is the asphalt concrete mixture formulation which includes choosing the asphalt concrete grain composition and the optimal amount of bitumen (Table 3) followed by shaping and testing the manufactured samples.

Asphalt concrete mix A 16Vn was chosen for the base. Initially, the mineral asphalt mixture was selected, and then the optimum amount of initial bitumen and modified bitumen was determined.

Asphalt mixtures were based on the same granulometric composition. One series of samples was prepared on the original BND 70/100 grade bitumen, the second series used the modified CNT bitumen.

The following processes are included in the asphalt mixture preparation technology:

1. Preparation of asphalt concrete mixture based on the initial binder – BND 70/100 grade bitumen in the mixing unit in the lab.
2. Preparation of asphalt-concrete mixture based on the obtained modified binder in a mixing unit in the lab.

3. Production of laboratory samples of a given size in the required quantity for the study (Fig. 2).
4. Testing of the obtained samples (Fig. 3).
5. Results analysis

***Table 3*. Selection of the composition of asphalt concrete mixture A 16Vn**

Complete passes, %	Grain size, mm, at most							Amount of binder (over 100%)
	22.4	16	11.2	4	2.0	0.125	0.063	
Grain composition acc. to GOST R 58406.2-2020	100	90-100	70-85	37-58	25-40	7-20	5-10	-
Grain composition acc. to the recipe	100	98.7	75.8	49.0	36.9	9.5	7.7	5.1
Grain composition, real BND 70/100	100	97.11	79.77	53.16	37.17	11.00	8.10	5.1
Grain composition, real BND 70/100 + CNT	100	97.44	77.52	52.55	38.84	10.66	8.04	5.0
*Values			**±5.0**	**±5.0**	**±5.0**	**±3.0**	**±3.0**	**±0.4**

Note: *- maximum permissible deviations of individual parameters from the recipe.

Fig. 1. Testing of bitumen grade BND 700/100

Fig. 2. Production of asphalt concrete samples

The research was using samples from asphalt-concrete mixture of the specified type based on oil road bitumen of the specified grade, as well as samples from asphalt-concrete mixture of the same type based on modified bituminous binder. This was followed by the analysis of the obtained results.

The experiment revealed a significant improvement in the main parameters of the asphalt mixtures, and the results showed maximum permissible deviations in the amount of binder in the asphalt mixture and in the main parameters. Moreover, the most important thing that has been achieved is a significant increase in rut resistance when rolling a loaded wheel (see Fig. 3).

RESULTS

Based on the data obtained, it can be concluded that with the help of bitumen modification, it is possible to solve a number of problems arising during the construction of asphalt concrete layers and during the operational phase of the road surface.

The tests of the molded samples of asphalt concrete revealed a significant improvement in the main parameters of the asphalt mixtures, and the results stayed within maximum permissible deviations in the amount of binder in the asphalt mixture and in the main parameters. And the most important thing that has been achieved is a significant increase in rut resistance by rolling a loaded wheel [13].

Test results of asphalt-concrete mixtures A16Vn are given in Table 4.

Table 4. **Test results of asphalt concrete mixture A 16 Vn. Key indicators**

Names of indicators	Unit of meas.	Maximum permissible deviations of individual values from the recipe	GOST requirements R 58406.2-2020	Results proj.	Actual results BND 70/100	Actual results BND 70/100 + CNT
Bulk density	g/cm3	-	-	2.695	2.692	2.706
air voids content	%	± 1.2	2.5-4.5 incl.	3.0	3.24	3.01
Voids in Mineral Aggregate (VMA)	%	-	at least 12.0	14.7	14.8	14.3
Voids filled with bitumen binder (VBB)	%	-	67-80	79.9	78.14	78.95
Average track depth	mm	-	at most 4.5	1.5	3.23	1.3
Water resistance		-	at least 0.85	0.87	0.87	0.87
Maximum density	g/cm3	-	-	2.777	2.782	2.790

Fig. 2. Production of asphalt concrete samples Fig. 3. Testing of asphalt concrete samples according to GOST R 58406.2-2020

CONCLUSIONS

Carbon nanotubes can be used to create a new composite material with unique properties and characteristics, which will ensure its use in the production of high-quality and reliable in operation systems and materials. Carbon nanotubes, which have close to the best mechanical properties, are considered as an effective means to improve the strength properties of composite polymeric materials. Nanotubes introduced into the asphalt mixture reinforce it, turning it into a composite material. Nanotubes behave like a network or matrix that binds the entire asphalt mixture together [4].

During the research:

1) The possibility of using inorganicbinders as road bitumen modifiers has been proved.

2) Introduction of 2% of carbon nanotubes into road bitumen has yielded an organic binder with the improved operational properties.

The use of asphalt concrete on modified bitumen will increase the service life by 5 years, as well as reduce the cost of road maintenance by road organizations.

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