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Application of Thermo Soluble Capsules for The Superfine Bitumen Modifiers

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Abstract: The study presents a model of the thermosoluble capsule for the use of carbon bitumen nanomodifiers. As carbon nanomodifiers we offered to use various materials and methods of preparation. We established the optimal method of administration and distribution of such nanomodifiers in the bitumen due to the dispergation in the "medium-bearer" industrial oil. We identified the basic changes in the deformation properties of asphalt concretes with the use of nanomodified bitumens. We determined the most effective material and shape of the capsule. We investigated the effect of the capsule material on the asphalt concrete properties.

Key words: Modified bitumen, carbon nanomaterials, thermosoluble capsule, fullerene-containing modifier, fullerene-containing soot

INTRODUCTION

Using the modified organic binding materials in the road construction is one of the promising areas that enable to provide coating with a maximum resistance to fatigue breakdowns, plastic deformations, resistance to changes in the diurnal temperatures as well as seasonal cycles. It is known that the price of modified bitumen is above by 40-60% on the average but it is due to the fact that the bitumen percentage in the asphalt concrete is 5-7%, so the price for construction of 1 km road coating rises by not >1%. Given the fact that there is an increase in the service life of the road by 2-3 times at the application of modified bitumen, the use of modified bitumen are economically justified and their study is quite relevant.

Basically we used two main methods, depending on the preparation stage, to produce the modified binding materials: method of compounding at the time of production of bitumen or modification of bitumen properties at the stage of production of finished marketable products (Evdokimova, 2015) (Fig. 1). Each of these methods has its own advantages and disadvantages.

The analysis showed that the use of chemical additives for the bitumen modification is a more effective way, since the introduction of additives enables the engineer to manage the properties required for the production of high-quality road-building composites, namely: increasing the adhesion forces between the mineral material and binding material, lowering the temperature of preparation and paving of asphalt mixture, increasing the thermal stability and structuredness of binding materials. The issues of production and application of modifying additives have been researched by many scientists at different times: Rudenskiy, Gokhman, Khozin, Zolotarev, Monismith, Shaw, Hveem and other Russian and foreign researchers.

At the same time, the current trends in the development of nanodispersed modifiers cause a large and stable growth of developments in this regard, including in the field of road materials science. The nanomaterials may serve as adsorbents, catalysts and reaction modifiers of chemical reactions, technological and structural properties of materials manufactured with their use. The improvement of material properties which is observed when using the nanopowders and nanoparticles is due to the physico-chemical processes and phenomena occurring on the surface of the interacting phases.

The use of nanotechnological approaches and nanosystems in the production of construction materials is a new approach to the choice of raw materials, technologies and the formation of structure of the construction composites. And the new materials include the new markets, an increase in production volume and an expansion of its product range. This increase in the competitiveness of domestic products and the important

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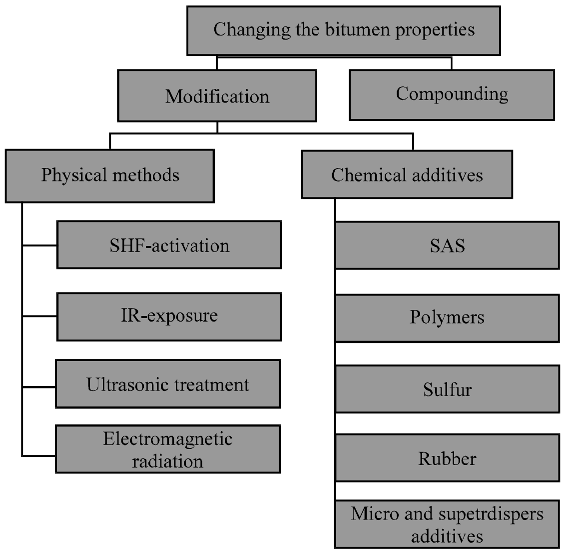

Fig. 1: The main methods of bitumen modification

problems of our time-energy saving and reduction of anthropogenic pressure of the industry of construction materials on the environment (Evdokimov and Losev, 2008).

MATERIALS AND METHODS

Carbon nanomodifiers for bitumen: The study of development trends in the nanoindustry of facilities now enables to conclude that one of the most promising fields of nanotechnology is the synthesis of Carbon Nano Materials (CNM). Today, when the nanocarbon technologies are being developed as one of the central areas of nanotechnology and when the very term nanocarbon (Vysotskaya *et al*., 2013) has become generally accepted in the world literature it is important to assess the results of scientific researches in this direction.

The analysis of the researches conducted showed that the carbon-containing additives are of particular interest among the CNM which include: carbon nanotubes, carbon black, modified carbon and the others which have a complex effect on the performances of strength, resistance to plastic deformations, water and frost resistance of asphalt concrete. Such modifiers have proven their effectiveness in dealing with the organic binding materials (Fedorov, 2013; Vysotskaya, 2013). Among the wide range of CNMfor the bitumen modification which are different in their nature and properties, such representative of carboxylic nanostructures as C60-fullereneis less studied. The prospects for the use of fullerenes are due to the specifics of their physical and chemical characteristics. A small amount of such additives can significantly alter the properties of the modified material. Given the fact that so far the experimental science has accumulated a wealth of information regarding the use of modifying additives, the issues of their rational and effective dosing of in bitumen become particularly relevant.

To carry out the researches, we considered two types of carbon nanomodifiers obtained in various ways in this study: by synthesis in a plasma reactor and at the integrated plasma processing of carbons. The synthesis of fullerene-containing modifier (here in after-the FCM) was carried out in the plasma-chemical reactor designed by the Kirensky Institute of Physics of the Siberian Branch of the Russian Academy of Sciences (Krasnoyarsk). The modifier composition includes: C60 and C70 fullerenes 10-12%, the rest amorphous carbon.

There is a more economical method of carbon modifier preparation this is the material obtained by the complex plasma processing of carbons. There is formed the synthesis gas ($CO+H_2$) activated carbon (sorbent) and as by-products, carbon nano materials fullerene containing soot (here in after the FCS) in a single unit at the plasma treatment of carbon under the action of the electric arc plasma of the electrode and carbon materials supplied for gasification. At that in the process of plasma treatment, the CNM can be formed not only from the electrode materials (by known methods) but which is also very important, from coal, passing the plasma treatment in the reactor (Buyantuev *et al*., 2013). The fullerene content in the obtained material C60 is 1.7-2%.

Application of carbon nanomodifiers: The modified bitumen based on the carbon nanomodifiers were prepared by introducing additives into the bitumen warmed up to working temperature of 130-140°C and by its mechanical mixing in a laboratory mixer of forced action "ML 2". The dosage of nanomodifiers varied in the range of 0.05-0.5 wt%.

After testing the asphalt concrete samples at the modified bitumen we have found that an increase in the CNM content to optimum 0.1% is accompanied by the effect of strength growth at 50°C by 65 and 46% for the FCS and FCM, respectively. By reducing the test temperature to 20°C the strength growth in the optimum zone is 33 and 26% for the FCS and FCM, respectively. The further stabilization of strength growth is due to the increased number of elements of the bitumen dispersed phase and the high sorption properties of amorphous carbon which is a component of additives, reducing the amount of membranous bitumen in the composite composition.

RESULTS AND DISCUSSION

The test results of shear-resistance of asphalt concrete evidence of its increase in the application of bitumen modified with 0.1 wt.% of the FCM, for 34% at 0.1 wt.% of the FCS for 28%. This is explained by the increased green strength and increased viscosity of modified bitumen. A resistance to the breaking loads is initially perceived by the formed units consisting of nanomodifiers and with an increase in the limit loads the force starts to be transmitted to the easily movable molecules of maltene fraction. At this time the dispersed aggregates start moving in the maltene mass, leading to the deformation of asphalt concrete samples. To simplify working with the finely divided additives we have offered a method for introducing the nanomodifiers by their pre-dispergation in the medium-bearer “industrial oil I-20A” and obtaining the fullerene-containing paste. To determine the optimal amount of CNM and rational mass of the medium-bearer we planned the active two-factor experiments for the FCS and FCM.

The experiment conditions are presented in Table 1. As an output parameter which is influenced by the experiment factors we have chosen the ultimate compressive strength MPa (Y) at a test temperature of 50°C. After processing the obtained experimental results, we received the dependences of the asphalt concrete strength on the amount of medium-bearer and the amount of CNM (Fig. 2 and 3).

We can identify from the experimental results the optimum areas of technological factors that indicate that the most effective is an increase in the concentration of nano-additive and medium-bearer. The minimum amount of medium-bearer does not affect a significant change in the performances of physico-mechanical properties of the asphalt concretes. However, this amount should be sufficient for the effective introduction and distribution of nano-additives in the composition of binding material.

Development of thermosoluble capsule for bitumen: To date, the form of delivery of modifying additives to the asphalt concrete plants depends on their aggregation state: powder and granular in bags, liquid in tanks or barrels with the volume of 200-1,000 L. For efficient operation, the production lines of asphalt concrete mixtures should contain the weight or volumetric feeders. Not all the asphalt cement plants carry out the modernization or retrofitting of existing lines with the feeders during the transition to the use of additives. Therefore, the workers face a range of problems associated with the use of additives in the preparation of asphalt concrete mixtures in terms of construction production. Furthermore, most of additives for bitumen are the 4th hazard class substances according to the toxicological properties. They have a characteristic odor and are irritating to the skin, mucous membranes of the respiratory tract and eyes. In this regard it is formed the need to develop the models and technologies of capsular dosage for safe and convenient operation with the additives.

As a material for the thermosoluble capsule it is the most effective to treat the polymeric unsaturated hydrocarbons, namely polyethylene, polypropylene and polyisobutylene. It is known that with an increase in the number of carbon atoms in the monomer link, there is the temperature increase of its softening which is associated with an increase in energy required for the thermal dissolution process. Therefore, it is more rational to use the High-Density Poly Ethylene (HDPE) as a material for the capsule having a melting point of 137°C. Selection of polyethylene as a material for capsule manufacturing is determined by its chemical inertness, low cost and availability. Also, this polymer has a high degree of structure ordering and a sufficient amount of natural voids necessary for the more active work with additives and organic binding materials.

In the preparation of asphalt concrete mixtures using bitumen of BND 90/130 brand, a permissible temperature range of binding material operation is 130-140°C and corresponds to the phase transition temperature of polyethylene which will result in the formation of a homogeneous composite.

Under the conditions of efficiency and ergonomics during transportation we selected the cubic model of thermosoluble capsule consisting of two parallel oriented and HDPE films bonded along the perimeter. Thus, the model takes the form of “cushion” with the additive inside it (Fig. 4).

The quantitative ratio of the capsule material and the asphalt concrete mixture depends on the additive used which is contained within the capsule. The average amount of additives of different nature is 0.2-0.8% from the bitumen weight that is 2.8 kg or 3-9 L when translated into 1 ton of bitumen. The number of HDPE which is necessary to produce the capsule with such volume is not more than 6%. To determine the effect of HDPE on the basic physical and mechanical properties of asphalt concrete we made the samples of dense hot fine-grained asphalt concrete, type “B” brand 2. The results received are shown in Table 2.

Table 1: Main characteristics of the experiment plan

Experiment factors	Factor indication	Lower level	Zero level	Upper level	Variation step
Amount of CNM, wt% from bitumen	X_1	0.01	0.055	0.1	0.05
Amount of medium-bearer (wt%)	X_2	0.05	0.175	0.3	0.10

Table 2: Basic physical and mechanical properties of the asphalt concretes

Asphalt concrete content	Average density (g cm^{-3})	Water saturatio (%)	Water resistance	Ultimate compressive strength, MPa, at the temperatures 50°C	20°C	0°C	Crack resistance (Mpa)	Shear resistance Internal friction coefficient	Shear adhesion
Control	2.41	1.8	0.96	1.3	3.2	9.1	5.5	0.81	0.49
With the empty capsule made from HDPE	2.35	1.6	1.05	1.6	3.4	9.2	5.8	0.84	0.37
Requirements GOST 9128-2013	no regulations	from 1.5-4.0	≯0.9	≯0.9	≯2.2	≯10	from 2.5-6	≯0.80	≯0.31

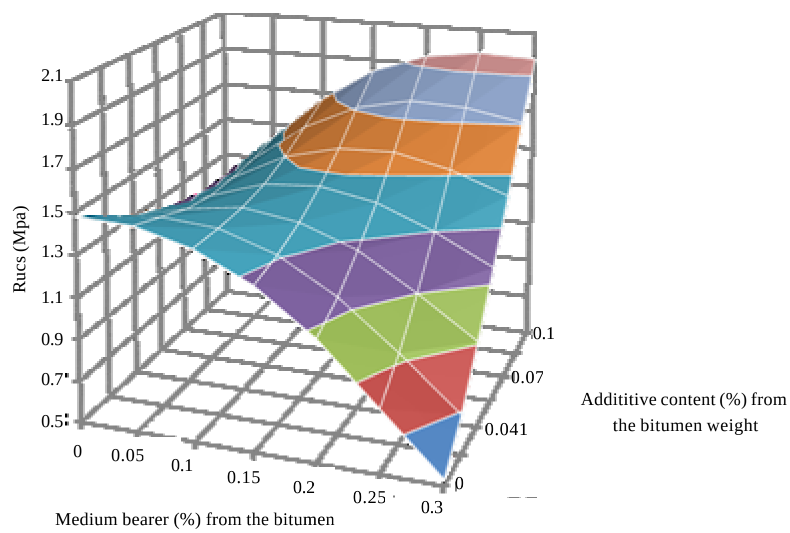

Fig. 2. : Dependences of the ultimate asphalt concrete strength at 50°C on the amount of medium-bearer and the amount of FCM. (Additive content, % from the bitumen weight: Medium-bearer content, % from bitumen weight)

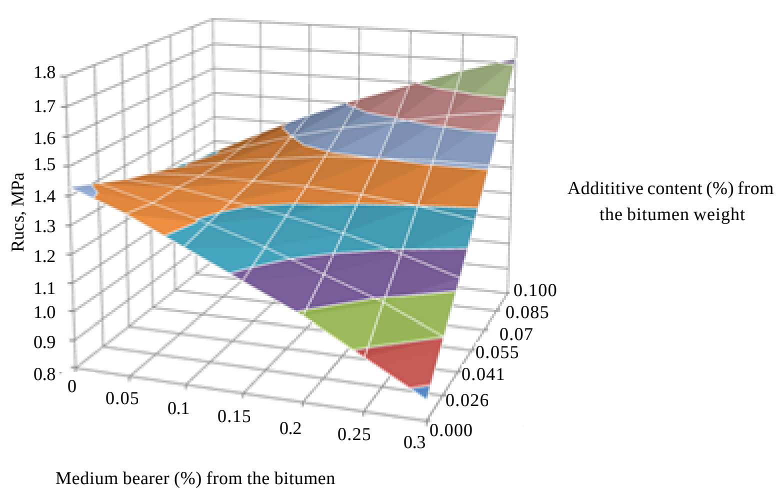

Fig. 3: Dependences of the ultimate asphalt concrete strength at 50°C on the amount of medium-bearer and the amount of FCS

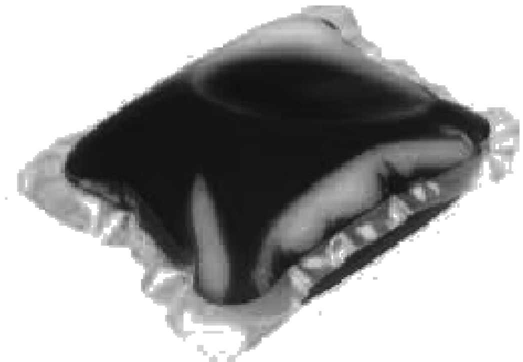

Fig. 4: Thermosoluble capsule model with the modifying additive for bitumen

CONCLUSION

According to the results of experimental data we have found out that the introduction of HDPE as a thermosoluble capsule composed of asphalt concrete, there is a change in the strength and hydro-physical properties that do not degrade the quality of asphalt concrete and are within the scope of regulatory documentation requirements. Thus, the proposed capsule model which is made of HDPE, enables to simplify the use of additives of different nature and aggregation state for the modified bitumen. The use of such capsules does not require the retrofitting of asphalt cement plant line and the effect of irritating components of additives on the bodies of workers is reduced to a minimum.

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