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The Effect of Modifying Additives on the Consistency and Properties of Bitumen Binders

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Abstract

The paper deals with the problems of improving the quality of binders used in road construction in Poland and Russia by modifying petroleum bitumen. The results of the study of the effect of the composition and content of various types of modifiers in the binder on the quality indexes of polymer-bitumen binders are presented. The recommendations on the choice of modifiers to solve the problems of road construction in Russia and Poland are given.

Keywords

Bitumen; cohesion; modified binders.

Introduction

The deteriorating state of roads is one of the most important problems in Poland, Russia and worldwide. The reason for this is mainly an increase in the road traffic and maximum permissible load on the axle of the vehicle, as well as adverse weather conditions. Taken together these factors lead to a rapid degradation of the road surface (plastic deformation, thermal and fatigue cracking). Increasingly, modified binders are used with the aim to improve functional properties of asphalt mixtures. Surface asphalt mixtures are viscoelastic materials, the characteristics of which depend greatly on the properties of the binder component of these mixtures. Unmodified bitumen is characterized by a narrow range of viscoelasticity, which is evident in their rapid transition to the plastic state at positive ambient temperatures and the appearance of brittleness at low temperatures [1–7]. The viscoelastic properties of bitumen can be improved by appropriate modification. The choice of appropriate modifiers to achieve the recommended specifications and durability of asphalt mixtures for road surfaces is complex and requires a number of studies.

According to the data of Strategic Highway Research Program (**SHRP**) studies [2, 8, 9] conducted in the United States, damage to asphalt pavements depends greatly on the properties of binders used in them. The effect of binders characteristics is as follows: viscoplastic deformation (rutting resistance) – 40 %, fatigue – 60 %, low-thermal cracking – 90 %. These indicators relate to asphalt mixtures with unmodified binders. Note that abroad, particularly, in European countries, more than 80 % of the roads are constructed using the residual (non-oxidized) bitumen obtained as a residue in petroleum refining. In most cases in Russia oxidized bitumen obtained by blowing air through the sludge is used [10]. Quality indexes of residual bitumen are better than those of oxidized one. However, to improve the quality of bitumen pavements both in Russia and abroad they are subjected to the modification process. Worldwide the problem of search of modifiers for different operating conditions of road surfaces and quality indexes of raw bitumen is of considerable scientific interest both

in terms of the durability of roads, and from the point of view of cost reduction of the obtained binders.

The aim of this study is to investigate the influence of the composition and content of various types of binder modifiers on the quality indexes of a polymer-bitumen binder (**PBB**), which can be used for bitumen modification, produced in Poland and Russia.

These studies have been carried out at the Department of Road Construction of the Faculty of Civil and Environmental Engineering at Bialystok University of Technology (Poland), and at the Department of Polymer Processing and Packaging Production of the Institute of Technology and Town Planning and Roads of the Institute of Architecture, Construction and Transport at Tambov State Technical University (Russia).

Materials and Methods

Unmodified bitumen 35/50 and 50/70 produced at Gdańsk Oil Refinery Plant (**ORP**) and modified bitumen used in the production of road coatings in Poland were studied:

– binders modified with thermoplastic elastomer (**SBS**) (polystyrene-b-polybutadiene-b-polystyrene block copolymers) in the amount of 3, 5 and 7 % of additives to bitumen (the symbols used are: S-3, S-5, S-7 %);

– binders modified with Ethylene Vinyl Acetate (**EVA**) in the amount of 3, 5 and 7 % of additives to bitumen (the symbols used are: E-3, E-5, E-7 %);

– rubber-bitumen binders modified with 15, 17, 19 and 21 % additive of crumb rubber to bitumen (the symbols used are: G-15, G-17, G-19, G-21 %;

– modified binders “Modbit” 30B, “Modbit” 50B and “Modbit” 80C produced at Gdańsk ORP (the symbols used are: M30, M50, M80).

We also investigated the following binders used for the production of road coatings in Russia:

– unmodified bitumen 60/90 and 90/130 produced at Syzran ORP;

– bitumen 90/130 modified with high-pressure polyethylene (**HPP**) in the amount of 2; 4 and 6% wt. (the symbols used are: P-2, P-4, P-6 %);

– bitumen 90/130 modified with thermoplastic elastomer DST-30-01produced at the public corporation “Voronezhsintezkauchuk” [11] in the amount of 2; 4 and 6 % wt. (the symbols used are: D-2, D-4, D-6 %);

– bitumen 90/130 modified with adhesive additive AMDOR-10 in the amount of 0.1 и 0.5 % wt. (the symbols used are: A-0.1, A-0,5 %) [12];

– bitumen 90/130 modified with a complex modifier based on DST-30-01, high-pressure polyethylene and adhesive additive AMDOR-10 in the amount of 2; 4 и 6 % wt. (the symbols used are: K-2, K-4, K-6 %).

Bitumen binders were subjected to the process of short-term oven aging (**STOA**) using Rolling Thin Film Oven Test (**RTFOT**), in accordance with EN 12607-1 Standard [13].

Qualitative characteristics of modified binders in the European Union and Russia are determined in accordance with Standards [14–16] and have some differences.

The parameters characterizing the cohesion of binders based on residual bitumen (Poland) were obtained by the following laboratory tests [14]:

– penetration tests at temperatures of 5, 15, 25 °C;

– study of dynamic viscosity on Brookfield Viscometer at temperatures of 90, 110, 135 °C;

– study of softening temperature;

– study of the breaking point on Fraass apparatus;

– study of tensile force in a ductilometer, with force measurement at temperatures of 5, 15, 25 °C and a tensile speed of 50 mm/min. During the tests the following parameters were investigated for cohesion assessment: ductility (the maximum elongation before the rupture), the maximum tensile force, tension energy.

The parameters characterizing the quality characteristics of the modified Russian bitumen were obtained by the following laboratory tests [15, 16]:

– penetration tests at 25 °C;

– study of softening temperature;

– study of the breaking point on Fraass apparatus;

– study of ductility (elongation) in a ductilometer at a temperature of 25 °C and a tensile speed of 50 mm/min;

– study of road binder elasticity.

Results

Table 1 shows the mean values of penetration of bitumen binders produced at Polish refineries at 5, 15 and 25 °C. Note that binders modified with SBS, EVA additives and rubber crumbs have a higher or equivalent stability to temperature changes as compared with the unmodified asphalt. Modified binders tested at 5 °C have a higher penetration index compared with the initial bitumen sample (50/70), testifying to their lower hardness at low temperatures. Penetration of modified binders increases with the increasing modifying additive.

Table 1

Mean values of penetration of Polish binders

Binders	Penetration [mm × 0.1]		
	5 °C	15 °C	25 °C
50/70	6.4	16.2	38.7
S-3 %	6.3	14.3	28.8
S-5 %	6.8	15.3	35.5
S-7 %	7.1	16.4	36.3
E-3 %	5.7	16.3	32.8
E-5 %	6.3	17.0	36.4
E-7 %	6.8	18.8	40.1
G-15 %	7.5	20.2	47.6
G-17 %	9.6	29.2	47.7
G-19 %	9.4	30.0	52.5
G-21 %	9.5	29.9	52.8
35/50	5.6	15.7	33.3
M30	1.2	9.9	30.0
M50	2.4	16.8	39.9
M80	2.2	16.8	39.8

Table 2

Mean values of dynamic viscosity of Polish binders

Binders	Viscosity [Pa·s]		
	90 °C	110 °C	135 °C
50/70	17.9	3.8	0.9
S-3 %	79.6	11.4	2.1
S-5 %	117.9	16.1	3.0
S-7 %	197.6	28.9	4.6
E-3 %	82.3	17.1	2.1
E-5 %	105.3	22.3	3.8
E-7 %	134.2	24.8	4.1
G-15 %	402.1	51.8	10
G-17 %	437	67.3	11.6
G-19 %	610.4	83.2	14.7
G-21 %	620.5	89.3	16.2
35/50	68.5	10.2	2.0
M30	60.2	12.1	1.8
M50	57.5	10.1	1.6

At a temperature of 25°C binders modified with SBS and EVA demonstrate increasing penetration simultaneously with increasing amounts of the modifier. From the studies presented in literature, particularly [1–3, 8] it follows that with increasing amount of the modifier the penetration of binders modified with SBS and EVA decreases. This is explained by the fact that binders used in the test were subjected to aging, and this process causes partial destruction of the bonds between SBS and EVA copolymers. The more is the amount of modifier in the binder, the more intensively the reaction of decomposition proceeds.

Table 1 shows that the least susceptible to temperature changes are the binders with the addition of SBS. Then one by one – a binder modified with EVA additive and rubber crumbs. The most sensitive to changes in temperature are modified binders Modbit produced at Gdansk Refinery.

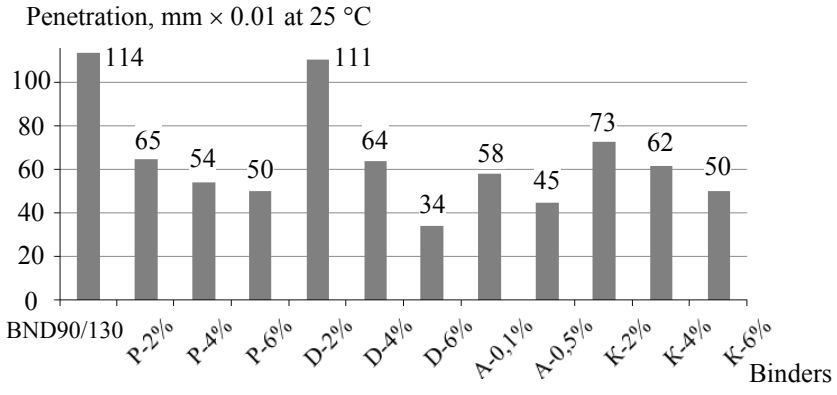

Fig. 1. Penetration of Russian bitumen binders at 25 °C

The study of modified bitumen produced at Russian refineries was carried out in the direction of developing a polymer-bitumen binder meeting the main requirements of the Russian Standard for PBB-60 based on block copolymers such as styrene-butadiene-styrene (polystyrene-b-polybutadiene-b-polystyrene block copolymers) [15], but having a lower cost due to the partial replacement of expensive thermoplastic elastomer by a cheaper HPP thermoplast in the composition of a complex modifier.

Figure 1 shows the mean values of penetration of Russian bitumen binders at 25 °C. The data presented in Fig. 1 indicate that an increase in the content of the modifiers reduces the penetration in comparison with the initial bitumen. Moreover, the modified binders P-2, D-4, K-2 and K-4 % comply with the prescriptions for PBB-60 [15].

The results of the study of dynamic viscosity of Polish binders presented in Table 2 show that modified binders are more viscous compared with the initial bitumen 50/70.

An increase in the amount of modifier leads to a significant increase in viscosity, especially at a temperature of 90 and 110 °C. At a temperature of 135 °C viscosity increase is also observed, but it is lower compared with the viscosity at different temperatures during the test. This adverse effect results in the necessity to raise the temperature not only during the production of asphalt mixtures, but also at laying the roadway.

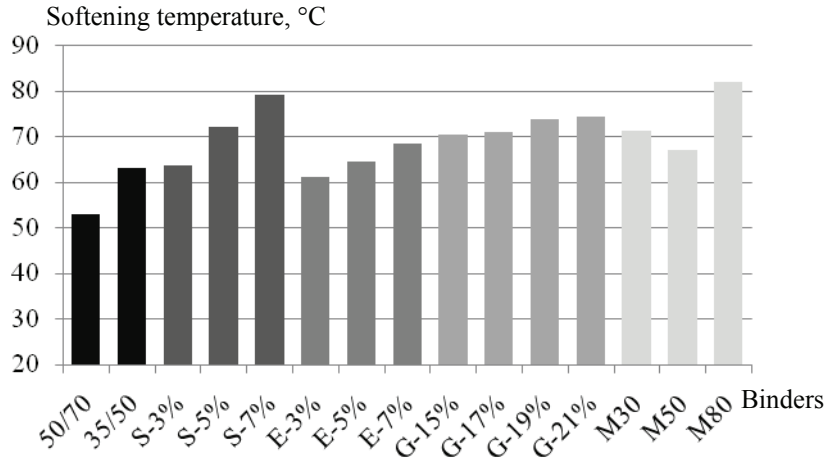

Fig. 2. Softening temperature of Polish bitumen binders

Figure 2 shows the mean values of softening temperature of the modified and unmodified Polish binders. The studies conducted show that an increase in the content of modifying additive leads to an increase in the softening temperature index. Modbit 80 °C and S-7 % have the highest values of softening temperature. It can be concluded that asphalt mixtures with these binders will be characterized by greater resistance to permanent deformations as compared with bitumen concrete mixtures with other binders. Lower softening temperature indexes are those of binders modified with crumb rubber and EVA.

Figure 3 shows the mean values of softening temperature of Russian binders before and after modification. The studies conducted show that an increase in the content of modifying additive leads to an increase in the softening temperature index. The binders of all brands except the initial and modified bitumen A-0,5 % meet the main requirements for PBB-60 [15].

Figures 4, 5 summarize the changes in ductility of Polish modified binders depending on the temperature.

It should be noted that ductility of modified binders is less sensitive to the changes in temperature relative to the unmodified bitumen. Bitumen modified with crumb rubber has the smallest change in ductility with temperature, and simultaneously it is characterized by the lowest values of tensility at higher temperatures. Bitumen modified with SBS additives, and modified binders Modbit produced at Gdansk refinery are characterized by the highest ductility values. The binders modified with EVA have a lower value of tensility.

Figure 5 shows ductility indexes of Russian binders before and after modification.

The studies conducted show that binders of all brands, except bitumen modified with PHP meet the regulatory requirements for PBB-60 [15]. Bitumen modified with thermoplastic elastomers, such as, SBS and complex modifiers demonstrate ductility growth at an early stage of an increase in the content of the modifier with further stabilization of this index.

The results of the study of the maximum tensile force of Polish binders (Fig. 6) testify to the fact that SBS-modified binder and Modbit have the highest values of this index in the range of the studied temperatures. This proves the presence of strong valence compounds in them. It can be concluded from the results that when the amount of additives increases, the maximum tensile force of modified binders also increases.

The results of the study of tension energy (Fig. 7) are very similar to the results of the maximum tension force of the modified Polish binders (Fig. 6). Binders modified with elastomers are characterized by the highest value of tension energy at temperatures investigated. This confirms the presence of strong

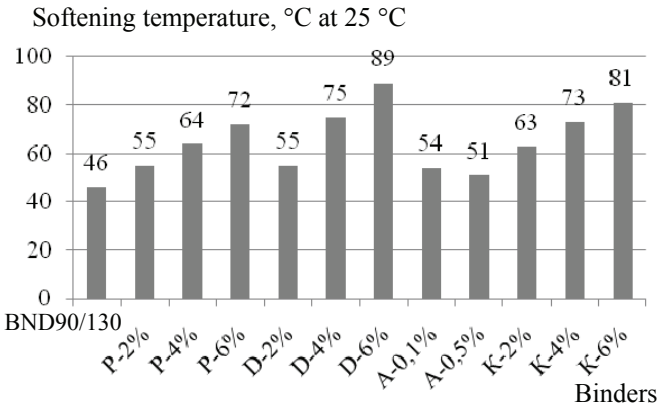

Fig. 3. Softening temperature of Russian bitumen binders

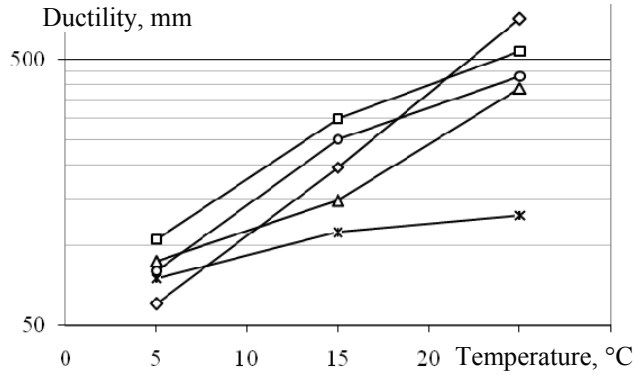

Fig. 4. Changes in ductility of Polish binders depending on the temperature:
◇ – 50/70; □ – S-7 %; △ – E-7 %; ✳ – G-17 %; ○ – M80

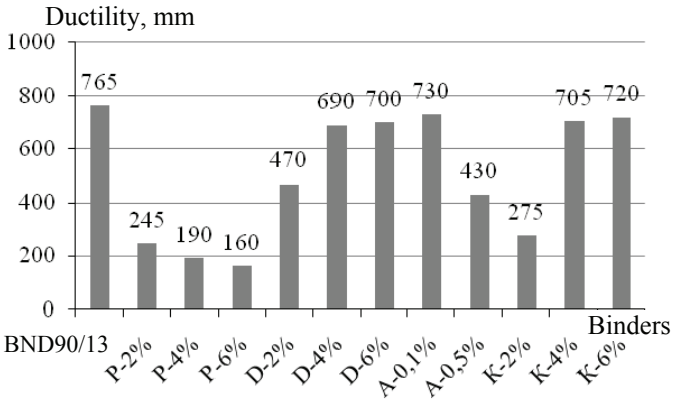

Fig. 5. Ductility of Russian binders

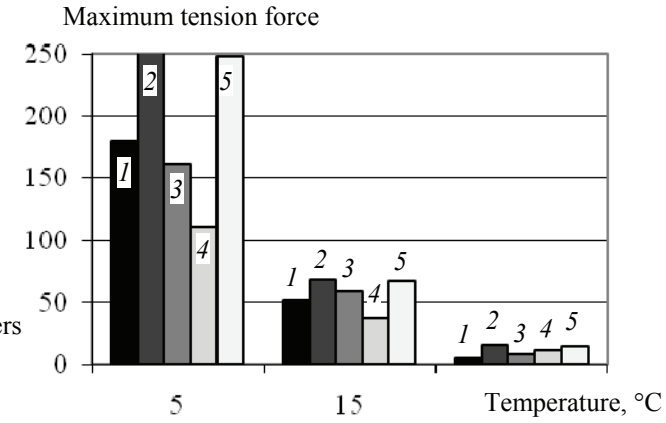

Fig. 6. The mean values of the maximum tension force of Polish binders:
1 – 50/70; *2* – S-7 %; *3* – E-7 %; *4* – G-17 %; *5* – M80

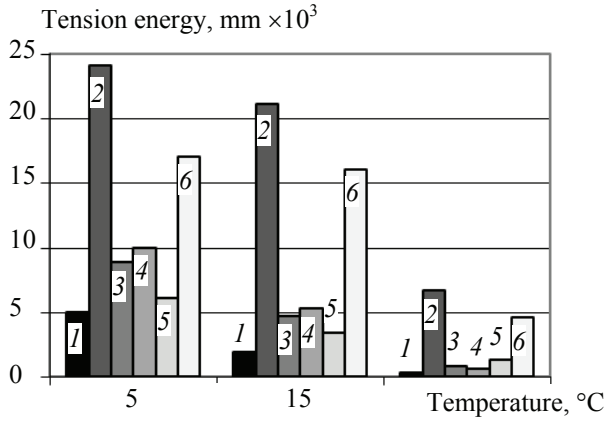

Fig. 7. The mean value of tension energy of Polish binders at temperatures of 5, 15 and 25 °C:
1 – 50/70; *2* – S-7 %; *3* – E-7 %; *4* – C-2.0 %; *5* – G-17 %; *6* – M80

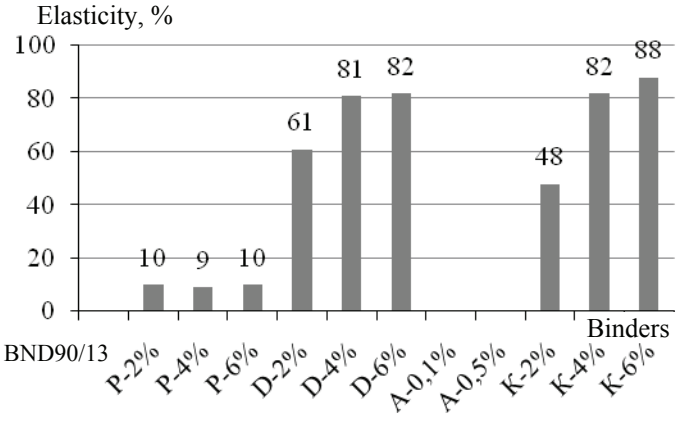

Fig. 8. The results of the study of Russian binders elasticity

intermolecular bonds. It can be concluded that with increasing amount of the modifier in the binder the tension energy growth of the modified binder is observed.

Figure 8 shows the results of the study of Russian binders elasticity at a temperature of 25 °C according to [16]. The studies conducted show that binders D-4, D-6, K-4 и K-6 % meet the elasticity regulatory requirements for PBB-60 [15].

The results of the study of breaking point of Polish binders are shown in Fig. 9, from which it follows that an increase in the amount of modifier positively reduces the breaking point of the binder. Binders Modbit 80C and S-7 % have the lowest (favorable) breaking point value. Bitumen concrete mixtures with their use will be characterized by greater resistance to cracking at negative temperatures.

System analysis of Russian modified bitumen indexes (Fig. 1, 3, 5, 8) testifies to the fact that the polymer-bitumen binder with complex modifier K-4 % meets regulatory requirements of the Standard [15]. Polymer-bitumen binder of this composition is recommended for use. Table 3 presents the results of the comparison of breaking point index according to Fraass of this PBB with that of the initial bitumen BND 90/130.

The studies have shown that the use of complex modifying additive allows for increasing the range of visco-elasticity by 35 °C in comparison with initial bitumen.

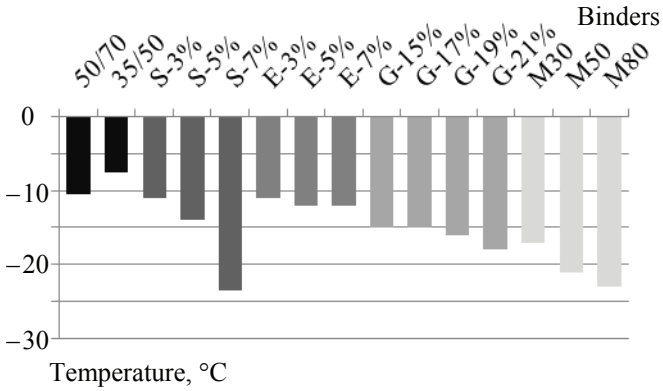

Fig. 9. The mean values of breaking point of bitumen binders produced in Poland

Table 3

Changes in the breaking point according to Fraass of Russian bitumen after modification

Binders	BND 90/130	K-4 %
Breaking point according to Fraass	–17	–24

Conclusion

The studies of binders produced both in Poland and Russia confirm the improvement of their quality characteristics in the process.

According to the results of the laboratory study of the cohesion of modified binders produced in Poland it should be noted:

– modified binders are characterized by a wide range of viscoelasticity in comparison with the original binder (before modification): by about 40 °C for binders modified with SBS, by about 30 °C for binders modified by rubber crumbs and by about 15 °C for binders modified by EVA;

– binders modified by thermoplastic elastomer SBS, Modbit have the best viscosity properties, then go rubber bitumen binders using crumb rubber and binders modified with EVA;

– optimal modifier content is as follows: SBS-7, EVA-7, rubber crumbs-17 %. Among the PBB produced on an industrial scale, it is Modbit 80C which has the best cohesion characteristics.

According to the results of studying the effects of different modifiers on oxidized bitumen produced in Russia the following conclusions can be made:

– modification of bitumen by thermoplastic elastomer DST 30-01 allows you to get quality indexes of polymer-bitumen binders required by Russian Standards, but the cost of the binder is rather high;

– increased modifier content leads to the reduction of penetration of the modified binders compared with the initial bitumen;

– an increase in the content of modifying additives results in an increase in the softening temperature index;

– in the modification of bitumen by high pressure polyethylene, there proceeds a sharp decrease in binders ductility below normative values of GOST R 52056-2003, and unacceptably low values of the binder elasticity index are observed;

– the formulation of a complex modifier in the composition of thermoplastic elastomer DST 30-01, high pressure polyethylene and adhesive additive has been found. The optimal content of this complex modifier in the polymer-bitumen binder is 4 %. This allows you to achieve the required quality index of the binder and reduce its cost;

– application of the complex modifying additive allows for increasing the viscoelasticity range in comparison with the initial bitumen by 35 °C.

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