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Crumb Rubber Modified Asphalt as a Surface with Extended Temperature Range.

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ABSTRACT

This paper deals with the research of high- and low-temperature properties of bitumen-rubber binder and rubberized asphalt concrete based on the first. A technique has been proposed for determining low-temperature deformability of the binder. There has been made an assessment of the sustainability of binder and surface based on it to the technological and operational aging, as well as environmental and economic aspects of the use of crumb rubber as a modifier. The applicability of crumb rubber as a modifier of the organic binder for the production of asphalt concrete based on it has been proved.

Keywords: modification, crumb rubber, bitumen-rubber binder, temperature range of reliable performance, crack resistance, rutting resistance.

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INTRODUCTION

Considering a huge territory of the Russian Federation, characterized by a wide range of operating temperatures, one of the ways to increase the transport and operational performance of pavements is to modify bitumen with different polymeric additives in order to extend the temperature range of reliable performance of asphalt concrete pavements. Search for the most effective modifiers, optimization of formulations of modified bitumen, polymer-bitumen emulsions, as well as analysis of the appropriateness of their use, started in the 50s., continues to this day. In the 60s, the USSR launched a research on the applicability of shredded rubber from used tires to improve performance of asphalt concrete pavements [1-4]. Relevance of the widespread use of tire recycling products was dictated by the rapid growth of automobilization, which continues till present. At the same time, the regulatory requirements for crumb rubber used for modification of asphalt concrete mixes specify only requirements for granulometric composition (no more than 20% larger than 0.63 mm) and the absence of cord impurities [5], which reflect the features neither any chemical composition, nor structuredness of rubbers of different manufacturers of tires, which are grinded using various technologies.

MAIN BODY

In order to investigate the applicability of crumb rubber, we have taken a modifier as effective one to obtain a composite bitumen-rubber binder, which is obtained by the method of high temperature shear grinding based on simultaneous exposure intensive compression, shear deformation and heating to a material, while the average size of a crumb is 5-50 microns. The results of comparative studies of the properties of bitumen-rubber binder obtained, modified with 20% of crumbs (with relative viscosity 40 dmm), and regulatory requirements for polymer modified asphalt binder PMAB 40 and rubber-bitumen binder BITREK 40/60 are shown in Table 1.

Table 1: Comparative characteristics of rubber-bitumen binder

Name of indicator	GOST P52056 PMAB 40	BITREK 40/60	RBV
1. Needle penetration depth, 0.1 mm at 25°C: at 0°C	40-60 25	40-60 abnorm.	41 29
2. Ring-and-ball softening point, °C, no less than	56	58	67
3. Extensibility, at 25°C, cm, no less than: at 0°C	15 8	abnorm. 3	15 10
4. Brittle temperature, °C, no more than	-15	abnorm.	abnorm.
5. Flash point, °C, no less than	230	230	230
6. Adhesion	Sample 2	abnorm.	Sample 2

Data analysis shows that the bitumen-rubber binder exceeds regulatory requirements for both polymer modified asphalt binders and BITREK binder. At the same time, the indicator of brittle temperature is not standardized for bitumen-rubber binders, which is explained by heterogeneity of crumb rubber-bitum systemic combination.Rubber, unlike DST, is a crosslinked polymer, which macromolecules, however, do not lose the ability to straighten under tension and collapse into balls after removing the mechanical load, due to the large distance between crosslinks (Fig. 1).

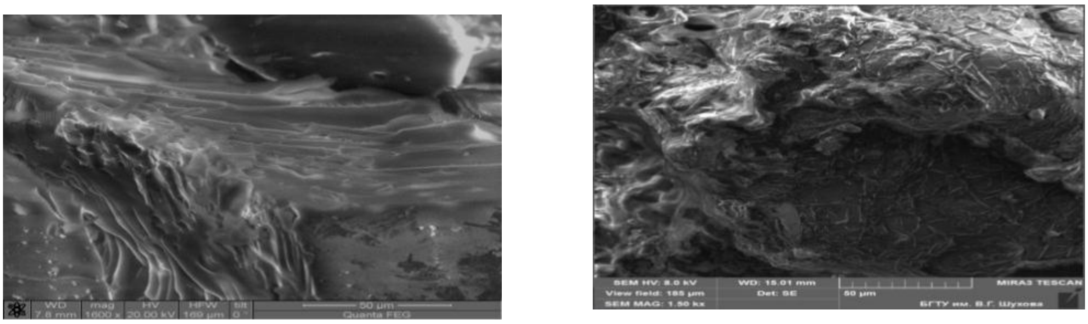

Figure 1: Macrostructure of polymer modified asphalt binder (a) and bitumen-rubber binder (b)

Bindings between macromolecules of rubber and organic binder asphaltenes can also form a net structure. As a result, properties of the RBV obtained are also determined by the properties of a net structure formed, which can stretch in the line of the load applied and takes up its significant portion [6]. Considering that properties of a binder having identical granulometric composition of asphalt concrete are mainly determined by the features of asphalt concrete performance, we have conducted comparative studies of the properties of stone mastic asphalt using the original bitumen, polymer modified bitumen and bitumen-rubber binder on main characteristics that define their reliable service within a wide range of operating temperatures.

Heat resistance was characterized by:

- For binders - characteristics of softening point, and for RBV (optional) - temperature of bitumen normal performance in the hot period by the “Superpave” procedure on Dynamic Shear Rheometer (DSR), in the controlled-voltage mode. This device is used for determining both viscous and elastic behavior by measuring the complex shear modulus (G*) and phase angle (δ) of organic binders (Table 2);
- For asphalt concrete - strength indexes at 20°C and 50°C, as well as coefficients of internal friction and adhesion in shear (Fig. 2-3).

Table 2: High temperature properties of rubber-bitumen binder

Index	BND	PMAB	RBV	Standard
Ring-and-ball softening point, °C	50	58	67	GOST 11506
Temperature of bitumen normal performance in hot periods without rutting (excluding aging), ^{0}C	-	-	65	“Superpave” regulation
Cohesion value, kg/cm2	9	10	14	abnorm.

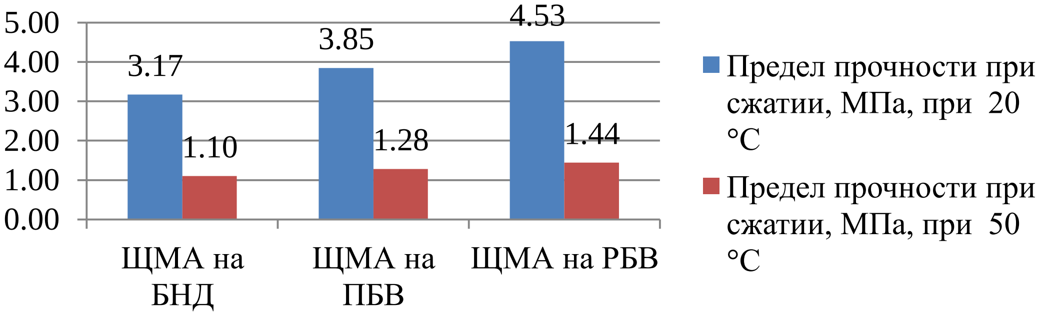

Figure 2: Strength indices of SMA-15 on different binders

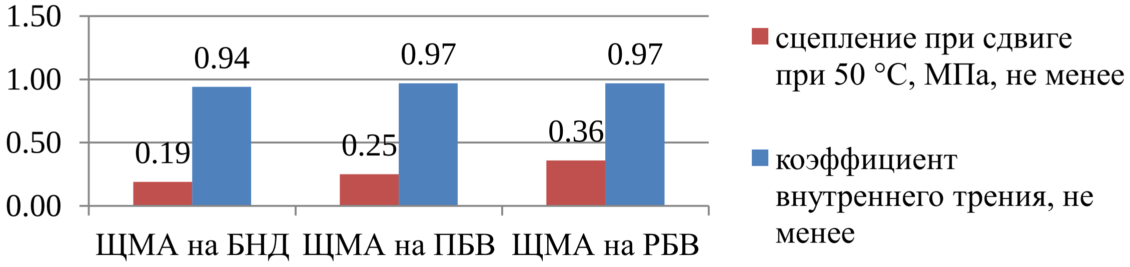

Figure 3: Indices of internal friction and adhesion in shift for SMA-15 in different binders

Index of compressive strength at 50^{0}C is 43% higher than in case of using the initial bitumen, and 28% higher than in polymer modified binder, indicating a more reliable performance of asphalt concrete pavements using RBV at high summer temperatures. Shear adhesion of RBV on SMA is 100% and 44% better than on the original and polymer modified bitumen, respectively, which allows predicting an increased rutting resistance of asphalt concrete pavements. Low-temperature properties of the binder were compared with the indices, standardized by GOST 52056-2003 (Table 3) and additionally by the method of determining the residual deformation proposed in this paper, since the occurrence of this type of deformation is especially dangerous for asphalt concrete pavements. After removing the traffic load and increasing the residual deformation up to 5 mm, the dynamic effect increases by 16 times, and the accumulation of residual deformation reduces significantly the service life of the entire pavement [7]. Data on deformation are shown in the diagram Fig. 4.

Table 3: Low temperature properties of bitumen-rubber binder

Index	BND	PMAB	RBV	Standard
Brittle temperature, °C	-17	-19	-	GOST 11507
Needle penetration depth, 0.1 mm at 0°C	20	24	29	GOST 11501
Extensibility, cm, at 0°C	7	9	10	GOST 11501

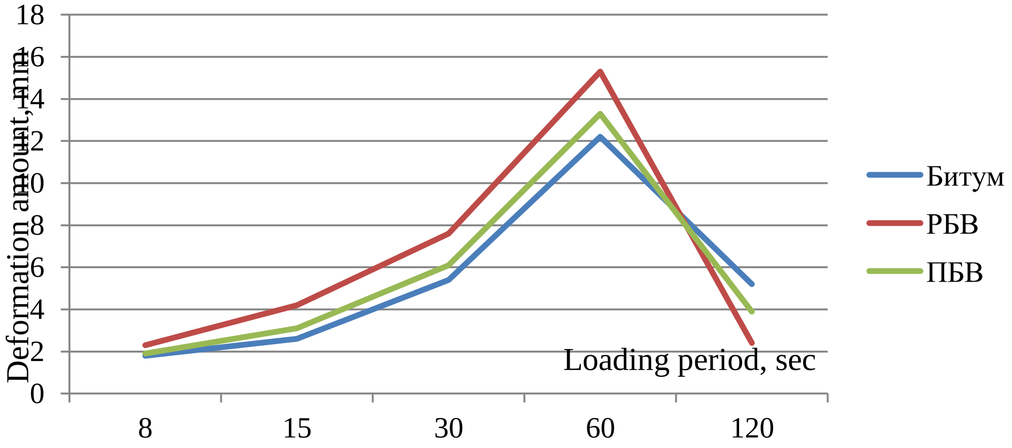

Figure 4: A comparative diagram of deformations and recovery of different binders at -17°C

Analysis of the results (the left part of the diagram) indicates a high deformability of RBV. Fixation of deformation after ending loading and the recovery of beam (right part of the diagram) shows that the proportion of residual deformation for RBV is 16% of maximum deformation, for PMAB is 30%, and for BND is 43%, which confirms a more higher deformability of RBV at low temperatures at significantly lower residual deformations. In addition, the RBV recovery curve has more acute inclination angle after unloading, which indicates a greater speed of reproduction of functional properties previously lost [8]. RBV-based asphalt concrete is characterized by increased deformability in low temperature conditions, which is confirmed by comparative data on crack resistance (Fig. 5).

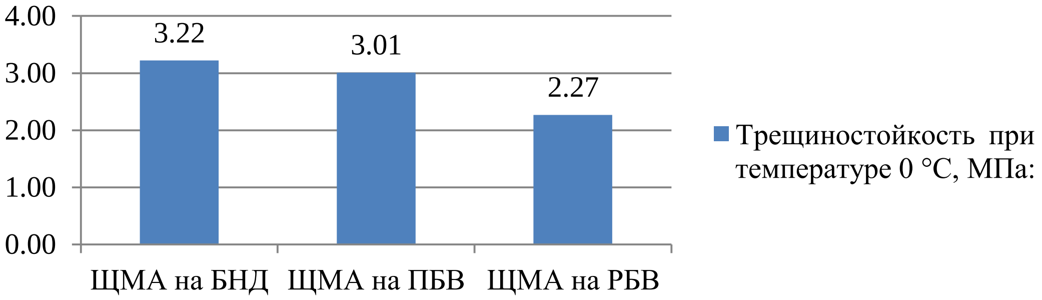

Figure 5 - Crack resistance of SMA-15 on different binders

Test results show that the bitumen-rubber binder is most resistant to both high and low temperatures. However, final conclusions about the deformability of the binder at low temperature, which characterizes the cracking temperature value, can be made only on the basis of technological and operational aging of organic binders, since the change in the chemical composition of the group due to aging results in increasing the brittleness of the binder, which leads to the destruction of asphalt concrete pavements. To determine these indicators, we have investigated the properties of the composite bitumen-rubber binder in accordance with the technological regulations of the American system “Superpave”. Federal Road Agency proposed a perspective plan of practical implementation of such tests in road construction in 2013.

A distinctive feature of “Superpave” technical specifications is that “Superpave” technique fully simulates the operating conditions of binders forming part of asphalt concrete, unlike the conditional indicators of applicable GOSTs. They are based on studies of organic binders in terms of three critical stages throughout the entire service life of the binder. Studies of the original binder present the first phase of its transportation and storage. The second phase corresponds to the technological aging of binder in the preparation of asphalt-concrete mixtures and construction of asphalt-concrete pavement. The third stage simulates operational aging of the binder. It follows from the “Superpave” technique that II and IV DKZ RF requires binder that corresponds to American brand PG 64-28 (64^{0}C – the highest temperature IV DKZ and -28^{0}C – the lowest temperature III DKZ). A comparison of actual RBV indicators has been performed according to the regulatory requirements of these regulations. According to ASTM standards, only modified bitumen should be used when selecting a binder with a temperature range of more than 900 °C.

To determine the value of a negative temperature of binder cracking after operational aging, the rheometer was used for bending beam test (BBR). If the stiffness of the binder is high during creep, it will result in cracking. Low-temperature cracking in RBV occurs at -43^{0}C, while the requirements for III DKZ specify only -28^{0}C [9]. Test results are shown in Table 4.

Table 4: Properties of rubber-bitumen binder

Name of indicator	Requirements for bitumen PG 64-28	Rubber-bitumen binder
DSR (temperature of bitumen normal performance in hot periods without rutting), ^{0}C	No less than 64 for IV DKZ	65
DSR (after RTFO furnace, simulating technological aging of bitumen), ^{0}C	No less than 64	64
DSR (after PAV, simulating operational aging during 8-10 years), ^{0}C	No more than 22	11
BBR (crack resistance at low temperatures), ^{0}C	No more than -28 for III DKZ	-43
Temperature operating range	92	108

Thus, the results of RBV studies under the technological regulations “Superpave” show that:

- a composite bitumen-rubber binder is slightly affected by technological aging, and its operational aging index is much lower than standardized one. This can be explained by the fact that the rubber in highly oriented state significantly complicates the diffusion of oxygen from the environment and inhibits oxidative processes;
- RBV has a wide temperature range of reliable operation -43^{0}C to +65^{0}C, which is 16^{0}C higher than specified by regulatory requirements.

Physical and mechanical properties of SMA-15 of identical granulometric composition with the use of binders compared are shown in Table 5.

Table 5:Physical and mechanical properties of SMA-15

Name of indicator	Indicator value for			
	SMA-15 on BND	SMA-15 on BND	SMA-15 on RBV	GOST 31015-2002
Compressive strength, MPa, no less than:				
at 20 °C	3.17	3.85	4.53	2.2
at 50°C	1.10	1.28	1.44	0.65
Shear resistance:				
internal friction coefficient, no less than	0.94	0.97	0.97	0.93
shear adhesion at 50 °C, MPa, no less than	0.19	0.25	0.36	0.18
Crack resistance — ultimate tensile strength under cracking at 0°C, MPa:	3.22	3.01	2.87	2.5-6.0
Drainage index, no more than, %	0.14	0.12	0.10	0.20
Water resistance under long-term water saturation, 15 days, no less than	0.86	0.89	0.93	0.85

Environmental safety during addition of crumb rubber when preparing asphalt mixtures was assessed by comparing the volume and mass fraction of CO (carbon monoxide) emissions [10]. Emission of CO is 80% higher when adding crumb rubber into asphalt mixing plant together with bitumen on hot stone materials ("dry modification technology”) than in case of adding crumb rubber included into bitumen-rubber binder.

The economic efficiency of the composite bitumen-rubber binder will be determined by:

- reduction in cost of materials for the preparation of RBV compared to traditional PMAB due to refusal of plasticizer and significantly lower price of crumbs compared to the polymer;
- refusal of stabilizing additives in the preparation of SMA due to the structuring properties of crumb rubber;
- increase of transport and operational performance of asphalt-concrete pavements, resulting in increased maintenance periods;
- resistance to technological and operational aging of bitumen-rubber binder, increasing service life of the pavement.

CONCLUSION

The research of applicability of stone mastic asphalt concrete on the composite bitumen-rubber binder as a coating layer in the construction and repair of roads is a prospective line of development in the road sector that will lead to significant cost savings by improving transport and operational performance of pavements.

SUMMARY

Analysis of data submitted shows improvement in all standardized parameters of RBV-based asphalt concrete due to the properties of bitumen-rubber binder used, which increases strength and shear resistance at high temperatures, and, hence, the resistance of the pavement to rutting, higher deformability and cracking at low temperatures. Furthermore, we have proved ecological properties and high economic efficiency of this material.

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