IOP Conference Series: Materials Science and Engineering

Asphalt concrete modified by rubber crumbs in transport construction.

IOP Conf. Series: Materials Science and Engineering **327** (2018) 032019 doi:10.1088/1757-899X/327/3/032019

Asphalt concrete modified by rubber crumbs in transport construction.

G S Duhovny, AV Karpenko

Belgorod State Technological University named after V.G. Shukhov, 46, Kostukova St., Belgorod, 308012, Russia

E-mail: karpenko-alisa@mail.ru

Abstract: High-temperature and low-temperature characteristics of the rubber-bitumen binder and rubber asphalt concrete based on it are researched. The determination method of binder's low-temperature characteristics is offered. The estimation of binder's and pavement's stability against technological and operational aging is evaluated. Estimation of environmental and economic aspects of using rubber crumbs is made. The possibility of using rubber crumbs as modifier of organic binder for production of asphalt concrete on its base is justified.

1. Introduction

Considering the vast territory of the Russian Federation, which is characterized by a wide interval of operational temperatures, one of the ways to increase traffic-operational characteristics of road pavement is the modification of bitumen by various polymeric additions in order to extend the temperature interval of the reliable operation of asphalt concrete pavement. Search for more effective modifiers, testing them to find the best recipes of the modified bitumen and polymer-bitumen emulsions, and analysis of their usefulness, which was started in the 1950's, are still under way.

Research of possibilities to use rubber from shredded tires was started in the 1960's in the USSR in order to increase the efficiency of asphalt concrete pavement. [1-4]. The rapid growth of motorization (that still is under way) had dictated the relevance of the large-scale use of the tire-recycling production. In rubber crumbs' regulatory requirements, there are requirements concerning only grain-size (not more than 20% and not larger than 0.63 mm) and absence of cord admixtures [5], which do not represent main features of neither a chemical composition nor a granularity level of rubber from different tire manufacturers, whose shredding is made by different methods.

2. Main Part

In this work, rubber crumbs are taken as an effective modifier; to get the compositional bitumen-rubber binder and to research the possibilities of crumbs, the modifier should be used. Rubber crumbs are produced by the shredding method of high-temperature shifting that is based on simultaneous pressure on material from the intensive compression, shifting-based deformation and heat. An average size of the crumb is 5-50 microns.

Comparative test results of the RBV rubber-bitumen binder, modified with 20% crumbs (funnel viscosity = 40 dmm) in accordance with the regulatory requirements and in comparison with polymer-bitumen binder PBV 40 and rubber-bitumen binder BITRACK 40/60, are shown in Table 1.

Table 1. Comparative characteristics of rubber-bitumen binder.

Parameter	GOST P52056 RBV 40 binder	BITRACK 40/60 binder	RBV binder
Depth of needle penetration, 0,1 mm - at 25°C:	40-60	40-60	41
- at 0°C	25	Not reg.	29
Softening point by ring and ball, °C, - not lower	56	58	67
Expansibility, at 25°C, cm, - not less	15	Not reg.	15
- at 0°C	8	3	10
Fragility point, °C, - not higher	-15	Not reg.	Not reg.
Flash point, °C, - not lower	230	230	230
Adhesion	Sample 2	Not reg.	Sample 2

Data analysis shows that the RBV binder exceeds regulatory requirements for the PBV binder, which are the same requirements as those for the BITRACK 40/60 binder. The temperature requirement is not regulated for the rubber-bitumen binder because the rubber crumbs-asphalt combination is heterogeneous. Rubber, unlike DST, is a crosspolymer, but due to a large distance between crosslinking, macromolecules preserve their ability to straighten up when extended and to curl up into balls after removal of the mechanical load.

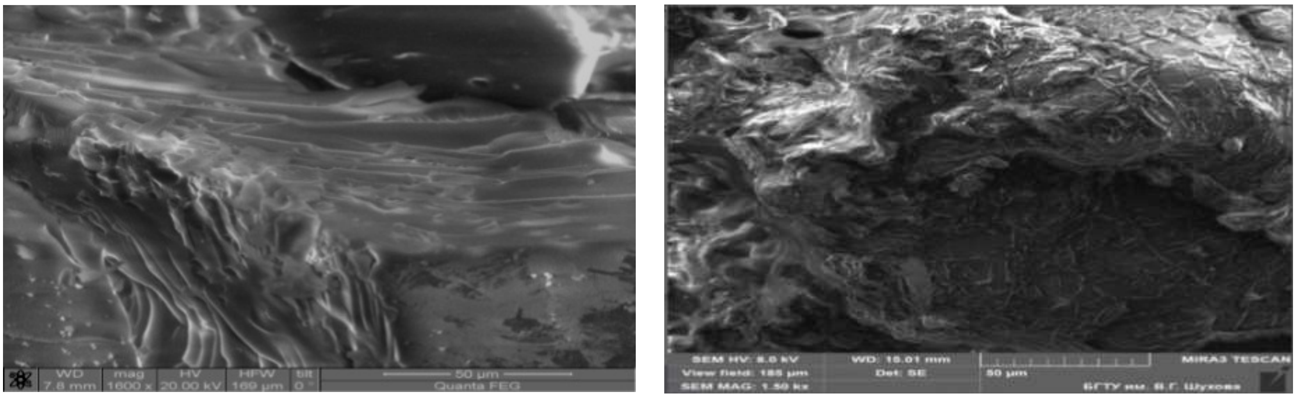

Figure 1. Macrostructure of polymer-bitumen (a) and rubber-bitumen (b) binders

Connections between rubber’s macromolecules and asphaltenes of the organic binder can create a cross-linked structure. As a result, characteristics of the produced RBV are determined by characteristics of the cross linked structure, which can extend in the direction of the applied load and can be perceived as its significant part [6].

Taking into account the fact that with the identical grain-size composition of asphalt, concrete characteristics in general, peculiarities of asphalt concrete determine operability, the comparative studies of macadam and mastic asphalt concrete were made on the original bitumen, bituminous polymer binder and the rubber-bitumen binder according to the main characteristics, which define their reliable operation in a wide interval of operational temperatures.

Heat resistance was characterized:

– For binders – by characteristics of the softening point, and for RBV (additionally) by bitumen's normal operation temperature in the heat period by the «Superpave» method using dynamic shifting rheometer DSR in the controlled tension mode. This device is used to define viscous and elastic behaviors by measuring complex shear modulus (G*) and phase angle (δ) of organic binders (Tab. 2).

– For asphalt concrete – by strength properties at 20°C and 50°C and, also, by the coefficient of internal friction and clutch shear.

Table 2. High-temperature characteristics of rubber-bitumen binder

Requirement	BND	PBV	RBV	Standard
Softening point by a ring and ball method, °C	50	58	67	GOST 11506
Normal operation temperature in the heat period without tracking (without considering aging), ^{0}C	-	-	65	«Superpave» regulation
Cohesion amount, kg/cm^2	9	10	14	not reg.

Ultimate compressive strength rate at 50 ^{o}C is 43% higher than that of the original bitumen and 28% higher than that of the bituminous polymer binder, which demonstrates a more reliable operation of asphalt concrete pavements with use of RBV in conditions of higher summer temperatures. Shifting cohesion for SMA on RBV is by 100% and 44% better than that on original and polymer bitumen respectively, which allows predicting higher tracking resistance for asphalt concrete pavements.

Low-temperature characteristics of binders were compared with requirements, regulated by GOST 52056-2003 (Tab. 3) and additionally by the residual deformation determination method that was offered in this work, because formation of this type of deformation is particularly dangerous for asphalt concrete pavements. So, after traffic load is over, with increasing residual deformation up to 5 mm, dynamic impact increases 16 times, and residual deformation accumulation lowers severely endurance of the entire asphalt concrete pavement [7].

Table 3. Low-temperature characteristics of rubber-bitumen binder.

Requirement	BND	PBV	RBV	Standard
Fragility point, ^{0}C	-17	-19	-	GOST 11507
Depth of needle penetration, 0,1 mm, at 0°C	20	24	29	GOST 11501
Expansibility, cm, at 0°C	7	9	10	GOST 11501

Experimental data indicate that RBV is highly resistant to both high-temperature and low-temperature conditions' effects.

However, conclusions about binder's deformability at low temperature that characterizes the cracking resistance's temperature value can be done only with considering technological and operational aging of organic binders, because alteration of chemical group composition due to aging causes an increase of binder's fragility that causes the destruction of asphalt concrete pavements. Characteristics of the compositional rubber-bitumen binder were researched in accordance with technological regulations of the American «Superpave» system in order to determine these requirements. A long-term plan to include such tests in practical road-building in Russia was offered by RosAvtoDor in 2013.

A distinctive feature of «Superpave»'s technological conditions is that, unlike conventional requirements of valid GOSTs, the «Superpave» method models fully operational conditions of binders in the asphalt concrete composition. They are based on tests of organic binders in terms of three critical stages throughout the life of the binder. Tests of the original binder are the first stage of its transportation and storage. The second stage is the technological aging of the binder in the process of batching the asphalt concrete mix and building the asphalt concrete pavement. The third stage simulates binder's operational aging.

The «Superpave» method suggests that for III and IV DKZ, the RF binder should accord to American trademark PG 64-28 (64^{0}C – the highest temperature of IV DKZ and -28^{0}C – the lowest temperature of III DKZ). Comparison of RBV's factual requirements was made with regulatory requirements of this regulation. Herewith, according to ASTM standards, when the binder with the temperature interval of more than 90^0C is chosen, only the modified bitumen should be used.

In order to determine the negative temperature value of binder's cracking after operational aging, the rheometer was used to test beam on BBR inclination. If binder's hardness during creep is high, cracking will take place. Low-temperature cracking in RBV occurs at -43^0C, while regulations for the authors' region cover -28^0C [9]. Test results are provided in Table 4.

Table 4. Characteristics of rubber-bitumen binder.

Parameter	Regulations for PG 64-28 bitumen	Rubber-bitumen binder
DSR (Normal operation temperature in the heat period without tracking), ^{0}C	Not less than 64	65
DSR (After treatment in the RTFO oven that imitates bitumen's technological aging), ^{0}C	Not less than 64	64
DSR (After PAV that imitates operational aging during the period of 8-10 years), ^{0}C	Not more than 22	11
BBR (cracking resistance at negative temperatures), ^{0}C	Not higher than -28	-43
Temperature operation interval	92	108

Thus, RBV's test results by «Superpave» technological regulations show that:

- the compositional rubber-bitumen binder is almost not affected by technological aging and the operational aging rate is significantly lower than the regulated one. This can be explained by the fact that rubber in a highly oriented condition significantly impedes oxygen's diffusion from external environment and inhibits oxidative processes;

- RBV has a wide temperature interval of reliable operation from -43^0C to $+65^0$C, which exceeds regulatory requirements by 16^0C.

Physical and mechanical requirements of SMA-15 with an identical grain-size composition and with use of compared binders are provided in Table 5.

Table 5. Physical and mechanical requirements of SMA-15.

Parameter	Requirement's value for			
	SMA-15 on BND	SMA-15 on PBV	SMA-15 on RBV	GOST 31015-2002
Compressive strength, MPa, not less than:				
at 20 °C	3,17	3,85	4,53	2,2
at 50 °C	1,10	1,28	1,44	0,65
Shifting resistance:				
coefficient of internal friction, not less than:	0,94	0,97	0,97	0,93
shear adhesion at 50 °C, MPa, not less than:	0,19	0,25	0,36	0,18
Cracking resistance – tensile strength of the split at 0 °C, MPa:	3,22	3,01	2,87	2,5-6,0
Drippage requirement, not more than, %:	0,14	0,12	0,10	0,20
Water resistance during prolonged water saturation, 15 days, not less than:	0,86	0,89	0,93	0,85

Ecological safety of injecting rubber crumbs during batching of asphalt concrete mixes was measured by comparing volume and mass fractions of CO (carbon monoxide) emission [10]. During rubber crumbs' injection in the asphalt mixing plant together with bitumen on hot stone materials («dry technology modification»), CO emission exceeds these regulations by 80% as compared to the technology of injecting rubber crumbs in the composition of the rubber-bitumen binder.

The ecological efficiency of using the compositional rubber-bitumen binder will be defined:

– by reducing the cost of materials used to batch RBV in comparison with traditional PBV by eliminating the need to use plasticizer and by reducing it significantly owing to much lower price of crumbs in comparison with polymer;

– by rejecting the use of stabilizing additives while batching SMA, because of structure-forming characteristics of rubber crumbs;

– by increasing road-service qualities of asphalt concrete pavements that lead to bigger intervals between maintenance;

– by increasing resistance to technological and operational aging of the rubber-bitumen binder, which extends the regulated life of the pavement.

3. Conclusion

Thus, the research of possibility of using macadam and mastic asphalt concrete based on the compositional rubber-bitumen binder as a coating layer in building and maintenance of roads is a promising direction in the road sector that will lead to the significant cost savings by improving road-service qualities of the pavement.

4. Findings

Analysis of the provided data shows an improvement of all regulated requirements of asphalt concrete with use of PBV because of the characteristics of the applied rubber-bitumen binder, which provides an increase in strength and shifting resistance at the higher temperatures and, therefore, pavement's tracking resistance, higher deformability and cracking resistance at negative temperatures. Also, ecological compatibility and high economic efficiency of this material are proved.

5. Acknowledgment

The article was prepared within the development program of the Flagship Regional University on the basis of Belgorod State Technological University named after V.G. Shoukhov, using equipment of High Technology Center at BSTU named after V.G. Shoukhov.

References:

[1] Racz B 1988 *Conf. Bitumen, Eger*, 12-14 Apr. Summ. Budapest 55-56

[2] Gezenswei L B Slepaya B M, Gochman L M 1973 *Avtomobylnie dorogi J.* **11**

[3] Nikolsky V G Krasotkina I A, Styrykovich N M, Bocharova O E 2010 *Avtomobylnie dorogi J.* **4** 62-64

[4] Khudyakova T S, Shapovalova N V, Kolerov L V, Popov S M 2010 *Monthly informational and analytical journal Avtomobylnie dorogi* **7** 944

[5] *Guidelines for construction of asphalt concrete mixes and application of shredded rubber [text]: app. 01.01.1985* (M.: Soyuzdornii)

[6] Tager A A 1978 *Physical chemistry of polymers* (M.: Chemistry)

[7] Duhovny G S 1978 *Research of hot asphalt concrete's characteristics depending on quality of bitumen derived from west-Siberian oil by various technologies: Dis. ... Ph.D* (Moscow).

[8] Sachkova A V, Duhovny G S 2013 Mir *Transporta J.* **1** (45) 60-63

[9] Karpenko A V, Duhovny G S, Miroshnichenko S I 2012 *Bulletin of BSTU named after V.G. Shukhov* **1** 22–24

[10] Spiridonov E S, Duhovny G S, Logvinenko A A, Horudzhaya N V 2009 *Bulletin of BSTU*

named after V.G. Shukhov **3** 113–116