UDC 662.1

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Investigation of Rubber Crumb from worn tires use to road constructions

Abstract

In this article was investigated ways of production of Rubber-Bitumen Compounds (RBC) and Rubber-Asphalt mix based rubber crumb (CR) from worn tires. The physico-mechanical characteristics of paving bitumen BND 60/90 modified with rubber crumb and spent engine oil. The structure of rubber crumb was characterized by optical microscopy. A possibility of using these rubber-bitumen compounds for preparing rubberized asphalt mixture was investigated experimentally. Physico-mechanical characteristics of RBC and Rubber-asphalt are determined by standard methods.

Keywords: Petroleum bitumen; Rubber crumb; Rubber-Bitumen Compounds; Rubber-Asphalt mix; Penetration; Softening point; Water saturation; Compression strength.

Introduction

Petroleum bitumen widely used in many industries, including road building constructions. Main problem with road building is the poor quality of bitumens used in asphalt-concrete pavements. One of the ways to improve the quality of the binders is their modification with polymers and rubber crumb [1]. Crumb rubber is a term usually applied to recycled rubber from automotive and truck scrap tires. During the recycling process steel and fluff is removed leaving tire rubber with a granular consistency. The utilization of spent rubber materials, including automobile tires, is currently one of the most important environmental problems on a global scale because of the rapid growth of the automobile industry. Tires are bulky, they are highly toxic, they do not undergo natural degradation and decay; therefore, they are accumulated in open landfills to occupy considerable ground areas or scattered in ravines, forests, and water bodies to pollute the environment [2-3].

According to available data, the world reserves of scrap tires are estimated at 25 million tons with an annual increment of 12 million (at least 7 million) tons. In Russia and the CIS countries, the annual volume of discarded automobile tires is greater than 1 million tons, about 1.5 million tons from China. For fully utilizing natural resources and protecting environment, many countries give priority to the reuse of waste rubber in recent twenty years [4-5]

Scrap tires are valuable secondary raw materials containing 65–70% rubber, 15–25% technical-grade carbon, and 10–15% high-quality metal. Thus, the efficient processing of scrap tires makes it possible not only to solve environmental problems but also to perform economically rational utilization processes [4]. A well known method is to burn the rubber waste to produce energy while producing cement. This kind of "recycling" has to be reduced in future. Due to its irreversible network, the different compounds and ingredients the recycling of rubber is not comparable with the recycling of plastics. [6]

Crumb rubber is often used in astroturf as cushioning, where it is sometimes referred to as astro-dirt. CR was used to remove ethylbenzene, toluene and xylene from aqueous solutions at room temperature [7]. Rubber crumb also goes into the manufacturing of several auto parts such as brake pads, brake shoes and vehicle acoustic

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 Printed in Kazakhstan

insulation. Small percentages of crumb rubber go into manufacturing new tires. A revolutionary nanotechnology process developed by the British group Dena Technology is gearing up worldwide to produce high quality building material as wood-replacement products from used tires. Also uses to paper-replacement materials are investigating [8].

Cut tires are used for the manufacture of drainage tubes, tapes for the protection of cables and pipelines, and soundproof walls along highways and for the protection of downslopes from erosion; Thermal methods for the secondary use of scrap tires are known, in particular, the combustion of tires to generate energy and pyrolysis under conditions of relatively low temperatures to produce light distillate, solid fuel, and metal. However, toxic organic substances, carbon monoxide, sulfur dioxide, soot, and volatile heavy metal compounds are released into the atmosphere with flue gases because of incomplete combustion. Therefore, this method is not widely used; In addition, the following technologies are available: the processing of tires to obtain rubber crumbs and powders for the manufacture of polymer mixtures and construction materials and the production of reclaim for the manufacture of rubber mixtures and asphalt-rubber compositions for insulating and roofing materials (soft and hard roofs and roof mastics) [4, 9, 10].

Schematic diagram of the utilization of tires as chips (rubber crumb) was offered (Figure 1). In the paper possibilities of rubber crumb use to road constructions are investigated. Crumb rubber modified bitumen can improve the heat-resistance, the crack-resistance at low temperature and the durability of bitumen. Asphalt concrete prepared with Rubber-Bitumen Compounds exhibits high performance, enhanced wear and heat resistance, and resistance to aging. As a result, the pavement quality grows, and its service life becomes a factor of 1.5 - 2 longer [1, 11, 12].

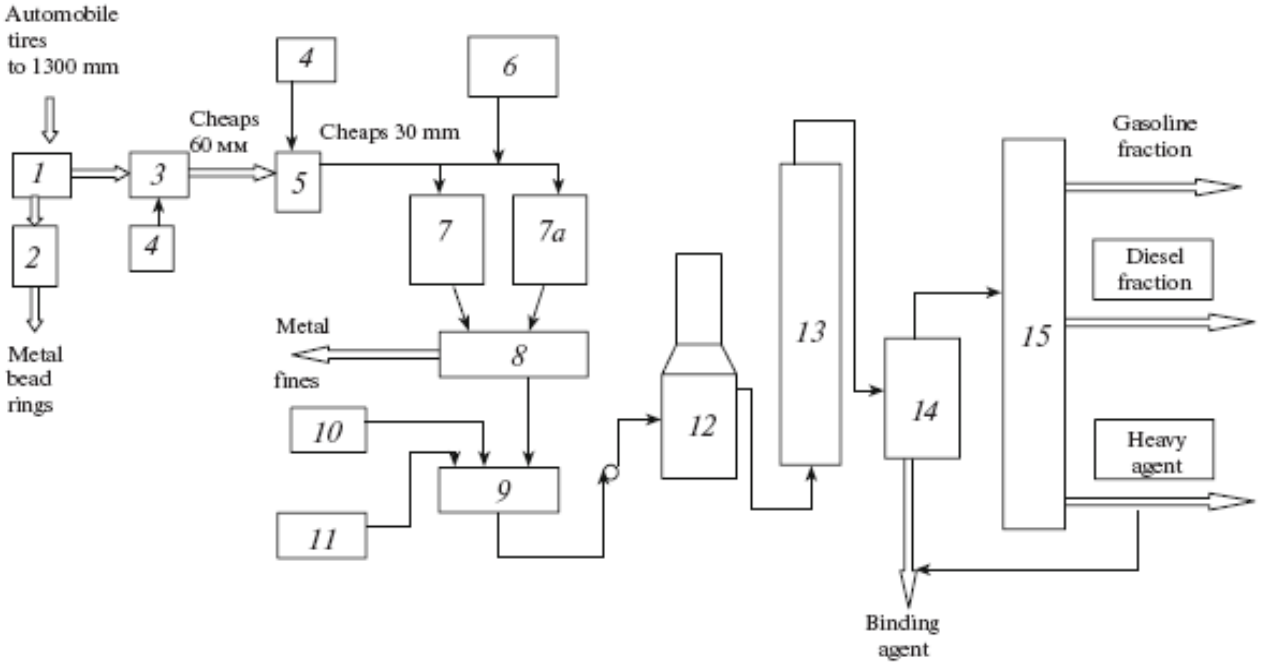


Figure 1 - Schematic diagram of the utilization of car and heavy-duty tires as chips: *1* sorting floor, *2* side strip remover, *3* cutter-type chipper, *4* electromagnetic apparatus, *5* hammer mill, *6* tank with a solvent spent oil, *7, 7a* chip fluidization reactor, *8* magnetic separator, *9* mixer homogenizer, *10* tank with petroleum residue, *11* zeolite shale crushing and dispensing unit, *12* furnace, *13* thermolysis reactor, *14* separator, and *15* rectification column [From literature 4].

Experimental Materials and Methods

Materials

When developing Rubber-Bitumen Compounds (RBC), it is necessary first to find conditions for introducing rubber crumb into a bitumen or plasticizer, under which the crumb would act not merely as filler but also as a modifier improving the bitumen properties [1]. At work were used standard paving bitumen BND 60/90, which physico-mechanical characteristics according to standard 22245-90 are: penetration at 25 ºC– 78·0,1 mm, softening point by method "ring and ball" - 47 °C, extensibility at 25 ºC - 96 cm. Spent engine oil from Car service.

Rubber crumb from spent tires (Kazakhstan Rubber Recycling LLP (in Astana)) which have

two different particle sizes: one of the rubber crumb is activated, particle size less than 0.6mm. It is showing on the figure 2. The other one is no activated, which particle size between 0.6mm and 1mm. It is showing on the figure 3. These figures were took in Laboratory of National Nanotechnology of Kazakh National University by Leica DM 6000 M optical microscope on optical reflection.

Preparation of rubber-bitumen compounds.

At first, rubber-oil mixture was prepared. Rubber-oil mixtures were prepared by mixing spent engine oil into rubber crumb with a ratio in 5:6, 1:1 and 3:2. After a day it used for preparing rubber-bitumen compounds. Bitumen samples were heated at 160-170 °C and variety content of (10; 15; 20; 25 wt%.) rubber-oil mixtures were added in bitumen. The compound was stirred for 5 minutes at165-180 °C.

Preparation of rubber-asphalt.

For the requirement of analyses mass of stone-mineral mixtures was 7 kg. Including stone – 35 wt.%, screenings - 58 wt.%, mineral powder – 7 wt.%. Stone-mineral mixtures were heated to 180 °C and RBC was added into mixture, which was stirred till get uniform black color.

Determination characteristics of samples

Physico-mechanical characteristics of Rubber-bitumen are established by standard methods: softening temperature (S) is determined by the method “Ring and Ball”, penetration (P) is determined by penetrometer, extensibility (D) is determined by ductilometer.

Physical and mechanical characteristics of the samples were determined in the testing laboratory of LLP "Asphaltbeton-1" according to the standard requirements of the Republic of Kazakhstan on the asphalt mixture ST RK 1225-2003, "Mixtures of road asphalt-concrete, airport, asphalt mix, technical conditions (specifications)." Analyses were carried out under the following conditions: temperature at 22 °C, humidity (water content) 69%, the pressure of 93.3 kPa.

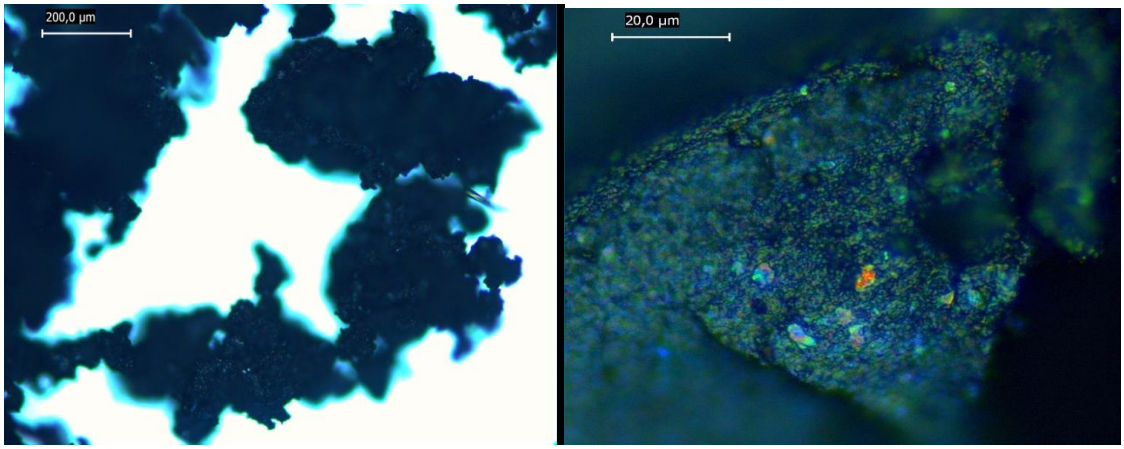


Figure 2 - Optical microscope images of rubber crumb with particle size less than 0,6 mm (activated)

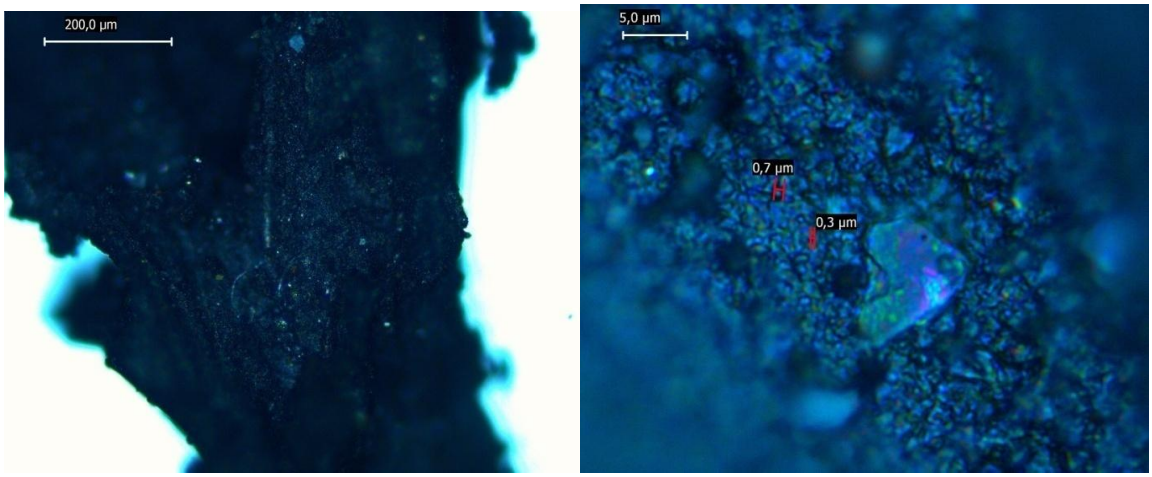


Figure 3 - Optical microscope images of rubber crumb with particle size 0,6-1,0 mm (no activated)

Results and discussion

Rubber-bitumen Compounds with activated rubber crumb.

We tested only rubber crumb modified bitumen, which was heated to 160±5 ºC and 5-10 percent by weight of activated crumb rubber was added in to bitumen. It was made by stirring for 5 min at 170-180 ºC. But, for the results of analyses on the physico-mechanical characteristics were shown poor indicator, because of lower extensibility. Ductility of rubber modified products was between 7 cm and 11 cm. in fact, all of the samples were mismatch standard requirements of the rubber-bitumen compounds.

The dispersion degree and the swelling capacity of crumb rubber in the bitumen have an important effect on improving properties of bitumen. The swelling of crumb rubber in bitumen is the process that light components in bitumen, such as saturated component, aromatic component, permeate into the crumb rubber. Obviously, the swelling can promote the formation of the elastic network of crumb rubber modified bitumen. So the better the swelling of bitumen to crumb rubber, the better the properties of crumb rubber modified bitumen [11, 13].

Aim of improving the physico-mechanical characteristics of RBC was used spent engine oil as additional modifying agent. Physico-mechanical characteristics of Rubber-bitumen compounds with activated rubber crumb and spent engine oil (Rubber:engine oil=1:1) are given table1.

Table 1 - Physico-mechanical characteristics of Rubber-bitumen compounds with activated rubber crumb (Rubber:engine oil=1:1).

Names of indicators	Base bitumen BND 60/90	RBC (a) R:O=1:1 10 wt%	RBC (a) R:O=1:1 15 wt%	RBC (a) R:O=1:1 20 wt%	RBC (a) R:O=1:1 25 wt%	Method of testing
Penetration at 25°C (*0,1mm)	78	90	127	126	170	According to standard 11501
Softening point (°C)	47	51	46	50	48	According to standard 11506
Ductility at 25°C (cm)	96	25	19	26,5	22	According to standard 11505
Standard accordance				RBC 90/130	RBC 130/200	

We can see in table 1, Physico-mechanical characteristics of RBC with 20 wt. % rubber-oil corresponds to grade of paving Rubber-bitumen compounds RBC 90/130 and 25 wt% is according to standard RBC 130/200. Physico-mechanical characteristics of Rubber-oil mixture (activated rubber crumb: engine oil=3:2) modified bitumen are given table2. The table 2 is showing Physico-mechanical characteristics of RBC with 10 wt. % rubber-oil corresponds to grade of paving Rubber-bitumen compounds RBC 60/90. Then RBC with 20 wt. % according to standard RBC 90/130 and 25 wt. % rubber-oil corresponds to grade of paving Rubber-bitumen compounds RBC 130/200. Whereas the 15 wt% crumb modified sample mismatch any standard of RBC.

Rubber-bitumen Compounds with no activated rubber crumb.

No activated rubber crumb modified bitumen was investigated same method and same experimental conditions with activated rubber-crumb modified samples. There are kindred phenomena, too: poor indicators, lower extensibility. Prepared samples were mismatch standard requirements of the rubber-bitumen compounds. At experimental work was used spent engine oil with no activated rubber crumb. When we use no activated rubber crumb (06-1) in ratio R:O=1:1 only one composition is a according to standard RBC 60/90. This is the 15 wt%, which is shown table 3.

Table 2 - Physico-mechanical characteristics of Rubber-bitumen compounds with activated rubber crumb

Names of indicators	Base bitumen BND 60/90	RBC (a) R:O=3:2 10 wt%	RBC (a) R:O=3:2 15 wt%	RBC (a) R:O=3:2 20 wt%	RBC (a) R:O=3:2 25 wt%	Method of testing
Penetration at 25°C (*0,1mm)	78	75	130	109	150	According to standard 11501
Softening point (°C)	47	58	47	55	46	According to standard 11506
Ductility at 25°C (cm)	96	19	31	17	25	According to standard 11505
Standard accordance		RBC 60/90	-	RBC 90/130	RBC 130/200	

Physico-mechanical characteristics of Rubber-bitumen compounds with no activated (06-1) rubber crumb (Rubber:engine oil=3:2) are presented table 4.

We can see from the table 4 the sample of RBC added 10 wt. % rubber-oil mixtures are according to standard RBC 60/90, with 15 wt. % and with 20 wt. % rubber-oil modified bitumen corresponds to grade of paving Rubber-bitumen compounds RBC 130/200.

Thus, all the tabulated results are allows knowing in ratio 3:2 rubber-oil mixture modified bitumen better than ratio of 1:1.

Table 3 - Physico-mechanical characteristics of Rubber-bitumen compounds with no activated rubber crumb (Rubber:engine oil=1:1).

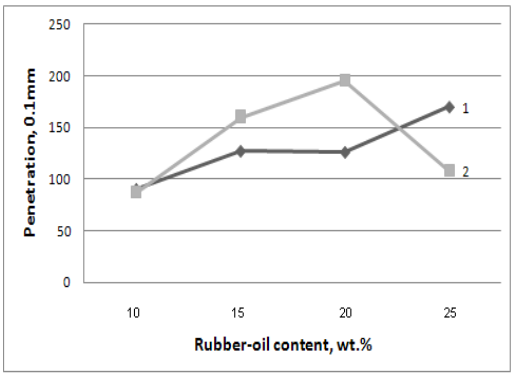
Names of indicators	Base bitumen BND 60/90	RBC (06-1) R:O=1:1 10 wt%	RBC (06-1) R:O=1:1 15 wt%	RBC (06-1) R:O=1:1 20 wt%	RBC (06-1) R:O=1:1 25 wt%	Method of testing
Penetration at 25°C (*0,1mm)	78	67	71	90	91	According to standard 11501
Softening point (°C)	47	50	59	51	58	According to standard 11506
Ductility at 25°C (cm)	96	12	13.5	12.5	11.5	According to standard 11505
Standard accordance			RBC 60/90			

Table 4 - Physico-mechanical characteristics of RBC with no activated rubber crumb (06-1)

Names of indicators	Base bitumen BND 60/90	RBC (06-1) R:O=3:2 10 wt%	RBC (06-1) R:O=3:2 15 wt%	RBC (06-1) R:O=3:2 20 wt%	RBC (06-1) R:O=3:2 25 wt%	Method of testing
Penetration at 25°C (*0,1mm)	78	87	160	195	108	According to standard 11501
Softening point (°C)	47	53	45	45	52	According to standard 11506
Names of indicators	Base bitumen BND 60/90	RBC (06-1) R:O=3:2 10 wt%	RBC (06-1) R:O=3:2 15 wt%	RBC (06-1) R:O=3:2 20 wt%	RBC (06-1) R:O=3:2 25 wt%	Method of testing
Ductility at 25°C (cm)	96	(06-1)	20	18	13	According to standard 11505
Standard accordance		RBC 60/90	R:O=3:2 10 wt%	RBC 130/200	-	

Comparisons characteristics of RBC with variety content of rubber crumb.

The resulting rubber-bitumen compounds (RBCs) exhibit elasticity, increased softening point, decreased brittle point, and enhanced strength. These properties allow RBCs to be used both as binders for asphalt concretes and as mastics for pavement repair.



1 – activated rubber modified bitumen (R:O=1:1)
2 – no activated rubber modified bitumen (R:O=3:2)
Figure 4 - Dependence of penetration on the rubber-oil content of RBC.

Physico-mechanical characteristics of prepared Rubber-bitumen compounds were compared. Dependence of depth of needle penetration on the rubber-oil content of RBCs is shown in figure 4. As seen from figure 4, with increasing content of rubber-oil mixture in bitumen, the penetrations of Rubber-bitumen compounds increase. It means the bitumen starts to harden.

The experimental results showed that the addition of crumb rubber in the bitumen increases the softening point of RBC slowly decreases, otherwise extensibility of RBC isn't more changing in any content of rubber-oil mixture.

The properties of crumb rubber modified bitumens, including the CR and crumb rubber with spent engine oil in ratio 1:1, are summarized in Table 5. By comparison, the properties of modified bitumen with the rubber-oil mixture are best, because of it is according to standard mark RBC 90/130. Its penetration and ductility is highest, while softening point decrease. And RC modified bitumen due to poor extensibility (7 cm) were mismatch standard requirements of the rubber-bitumen compounds. It can be describe elasticity properties of engine oil for preparing modified bitumen based rubber crumb.

Table 5 - Properties Comparison of activated Crumb Rubber Modified Bitumens.

Kind of modifier	Penetration	Softening point (25	Ductility
-	78	47	96
Rubber crumb, 10 wt.%	52	57	7
Rubber-oil mixture, 20 wt.%	126	50	26,5

Rubber-Asphalt with activated rubber crumb

Use of rubberized asphalt as a pavement material was pioneered by the city of Phoenix, Arizona on several area freeways in the 1960s because of its high durability. Since then it has garnered interest for its ability to reduce road noise [2].

Several samples of rubber-bitumen compounds were used for preparing hot asphalt mix, because of their best physico-mechanical characteristics in all of prepared RBC. Physico-mechanical characteristics of these samples are presented in table 6.

Table 6 - Physico-mechanical characteristics of Rubber-asphalt with activated rubber crumb.

Name of indicators	Asphalt mix with activated rubber crumb				Standard requirements
	№1 RBC R:O=5:6 20 wt.%	№2 RBC R:O=1:1 20 wt.%	№3 RBC R:O=3:2 10 wt.%	№4 RBC R:O=3:2 20 wt.%	
Medium density, g/cm^3	2,34	2,33	2,35	2,33	Not rated
Water saturation, %	0,7	0,5	0,4	0,7	For the dense type from 1,5 to 4,0
Compression strength, MPa, at 20 °C water-saturated	2,4	2,0	3,1	2,1	Not rated
Compression strength, MPa, at 50 °C	0,7	0,8	0,9	1,1	For the dense type, MPa, not less than: A – 1,5 B – 1,8
Compression strength, MPa, at 0 °C	5,7	2,3	7,6	6,9	No more than 13,0 for the A, B type of asphalt concrete:
Water resistance	0,89	0,83	0,97	0,89	Not less than 0,9
water resistant with prolonged water saturation	0,85	0,92	0,94	0,90	Not less than 0,8

As is evident from the table 6, medium densities of four samples are fundamentally identic (2,33 – 2,35). Compression strength of sample №1 at 50 °C lower than other. Whereas, all samples on characteristics of compression strength at 0 °C refers to the A, B type of asphalt concrete, which is no more than 13,0 MPa. On indicator of water resistance (0,89) of sample №1 and №4 was closest to standard. For the results of analyses on characteristics of water resistant with prolonged water saturation (not less than 0,8) were according to requirements of standard.

Rubber-Asphalt with no activated rubber crumb

Asphalt concrete were tested base of chosen rubber-bitumen compounds, which given table 7. For the results of analyses on characteristics of medium density of four samples are fundamentally identic, too. On water saturation at №2 and №3 are according to standard, whereas, result of sample №1 mismatch requirements of the norms. And sample №1 got lower indicator on compression strength, at 0 °C and 50 °C. We can see from the table 7 on characteristics of water resistant with prolonged water saturation (not less than 0,8) were according to requirements of standard. But, on indicator of water resistance at sample №2 refers to the standard requirements of asphalt concrete.

Table 7 - Physico-mechanical characteristics of Rubber-asphalt with no activated rubber crumb.

Name of indicators	Asphalt mix with no activated rubber crumb			Standard requirements
	№1 RBC R:O =5:6 25 wt.%	№2 RBC R:O =1:1 15 wt.%	№3 RBC R:O =3:2 20 wt.%	
Medium density, g/cm^3	2,30	2,31	2,28	Not rated
Water saturation, %	1,3	2,4	3,0	For the dense type from 1,5 to 4,0
Compression strength, MPa, at 20 °C water-saturated	1,5	2,3	2,1	Not rated
Compression strength, MPa, at 50 °C	0,6	0,8	0,8	For the dense type, MPa, not less than: A – 1,5 B – 1,8
Compression strength, MPa, at 0 °C	3,6	6,8	6,7	No more than 13,0 for the A, B type of asphalt concrete:
Water resistance	0,88	0,96	0,78	Not less than 0,9
water resistant with prolonged water saturation	1,0	1,2	0,93	Not less than 0,8

Conclusion

In the study production of rubber-bitumen compounds based on spent rubber items and spent engine oil, same time use it to prepare rubber-asphalt mixture were investigated. It is established that the quantity of entered binders depending on physical and chemical conditions, which was optimal composition of rubber-oil at a ratio of 3:2 and introduction to bitumen in amount of 15-25 wt.%. At that time, rubber crumb and spent engine oil use to road construction will allow the amount of rubber crumb produced by reclaiming facilities to be considerably increased and decrease environmental pollution with industrial wastes.

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Received 3 February 2012