Asphalt rubber as an alternative of polymer modified bitumen

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ABSTRACT. *In this paper it was determined if asphalt rubber can be an alternative to the polimer modified bitumen. Paper presents properties of various asphalt rubber binders obtained using two neat unmodified binders, two kinds of crumb rubber as well as different amount and types of plasticizers. Results of studies indicated that asphalt rubber display either comparable or better properties than polymer modified bitumen typically used in road constructions in Middle Europe. Presented results are part of an innovative research project supported by European Union funds.*

KEYWORDS: ***polymer modified bitumen, asphalt rubber, rheology***

1. Purpose and scope of work

Paper presents the results obtained during the study conducted under the project founded by the Innovative Economy 1.4-4.1 program supported by the European Union founds for the innovative undertakings in the enterprise sector, business and research and development background resulting in the improvement of the competitiveness of the Polish economy [5]. Applicant and coordinator of the project is the company Polski Asfalt Sp. Z o. o. Other participants of the project are Warsaw University of Technology, Group of Road Materials and Technology, TPA Company for quality assurance and innovations and Strabag Sp. z o. o [10].

The aim of the whole project was to develop and implement technologies for the production of crumb rubber modified bitumen and asphalt rubber hot mixes with improved rheological properties. According to the ASTM D 8-2009 (Standard Terminology Relating to Materials for Roads and Pavements), rubber modified bitumen (or asphalt rubber, according to US terminology) is defined as a mixture of bitumen binder, crumb rubber from waste tyres (at least 15% (by weight)) and additives lowering the viscosity, in which rubber components of modified binder ‘reacts’ with hot bitumen, significantly increasing its volume. It is commonly assumed, that asphalt rubber is a material and technological solution which will enable to produce pavements with improved durability, resistance to aging and, most likely, reduced noisiness, as compared to traditional technologies [1, 4, 8, 9, 11]. Rubber-modified bitumen can demonstrate properties comparable to polymer modified bitumen commonly used in road construction; production cost of rubber-modified bitumen can be lower than comparable polymer modified binders [3]. It is believed, that the developed asphalt rubber hot mixes can be eco-friendly products that enable the sustainable management of natural resources.

As a part of the whole project, properties of bitumen binders provided to modification and modifying additives were tested, as presented in this paper. Preliminary studies were carried out with rubber asphalt, then the modification process was optimized and basic properties of rubber modified bitumen were determined.

As a result, properties of reference polymer modified binders used in road construction in Poland were determined. The properties of polymer modified bitumen allowed comparative analysis of basic and rheological properties of rubber asphalt. The analysis of the obtained results allowed choosing, for further research, four asphalt rubbers with optimal properties.

The research project benefited from experiences presented at the Asphalt Rubber Conferences organized every three years by Jorge B. Sousa, Euroasphalt Eurobitume Congress, International Conference of Solid Waste Technology and Management Philadelphia, Transportation Research Board and numerous domestic and foreign papers on the use of asphalt rubber in road construction.

2. The research program of road bitumen and polymer modified bitumen

The research tests were carried on road bitumen (modified later with rubber) and polymer modified bitumen used as a comparative binder (reference samples).

2.1. Binder test methodology

Basic research of binders were performed according to PN-EN 12591 standard and PN-EN 14023. Advanced rheological studies were carried out in accordance to the SHRP methodology adopted to EN specifications: PN-EN 14770 (Dynamic Shear Rheometer) and PN-EN 14771 (Bending Beam Rheometer) methodology. Test in the BBR apparatus are a good indicator of the low temperature properties of bitumen [2, 6] while tests in the DSR apparatus is helpful to analyse bitumen properties in the intermediate operating pavement temperature [7].

2.2. Research tests of road bitumen

Research tests of road bitumen used for modification (bitumen 50/70 and 70/100) took into account variations in the properties of binders that occur during aging. The test program comprised of basic research and the rheological properties of road bitumen before aging, after technological aging (Rolling Thin Film Oven) RTFO, and after operational aging (RTFO and Pressure Aging Vessel) RTFOT and PAV. On each stage of binders aging the following properties were tested:

- determination of group composition: content of asphaltenes, resins and oils,
- penetration at 5°C, 15°C and 25°C,
- softening temperature by Ring & Ball method,
- brittleness temperature by Fraass method,
- temperature plasticity range,
- penetration index (PI),
- viscosity at 90°C, 110°C and 135°C by Brookfield method,
- determination of the m parameter (measured in the Bending Beam Rheometer (BBR)) at -6°C, -12°C and -18°C,
- determination of the S-value (measured in the BBR) at -6°C, -12°C and -18°C,
- determination the maximum temperature in the Dynamic Stress Rheometer (DSR), for which $G^* / \sin\delta \geq 1$kPa,
- determination in the DSR the value of G* modulus at -20°C, 0°C, 20°C, 40°C, 60°C and 80°C,

- determination in the DSR the value of phase shift δ at -20°C and 0°C, 20°C, 40°C, 60°C and 80°C.

2.3. Research tests of the polymer modified bitumen (reference bitumen)

The research program of the polymer modified bitumen PmB 25/55-60, PmB 45/80-55 and PmB 45/80 65 (reference bitumen) comprised of a similar range of studies as for unmodified 50/70and 70/100 bitumen, namely:

- basic tests and rheological properties of the original binders (nonaged)
- basic and rheological properties for RTFO aged bitumen
- basic and rheological properties for RTFO+PAV aged bitumen
- study of elastic recurrence and stability of storage
- examination of the microstructure in a fluorescent microscope to verify uniformity of dispersion of polymer. It is assumed that the dispersion of the modifier in the bitumen binder should be uniform and consistent across different aging processes.

3. Asphalt rubber

In order to conduct trial bitumen modifications, a special set of apparatus for the manufacture of bitumen rubber was built at Warsaw University of Technology. This apparatus consists of overhead stirrer with a propeller and disperser with a cutting head. Modified bitumen is placed in the temperature controlled container positioned on the hot plate.

3.1. Optimization of the asphalt rubber manufacturing process

A preliminary optimization of the modification process was carried out under laboratory conditions with regard to the following variables: modification time, temperature and technology, the sequence and duration of various consecutive modification stages and method of application of the modifying additives to the bitumen.

To produce a set of bituminous binder modified with rubber, the following materials were used:

- output bitumen 50/70, marked 50,
- output bitumen 70/100, marked 70,
- rubber granules, granulation 0,5 / 1,5 mm, from passenger car tires, marked G1,

- rubber dust, granulation 0 / 1, 0 mm, from passenger car tires, marked G3,
- rubber dust, granulation 0 / 1, 0 mm, from truck tires, marked G4
- a mixture of 50/50% (m / m) of G3 and G4 dust, marked G5,
- conventional plasticizer, marked QT,
- plasticizer of vegetable origin, marked OR.

In the process of bitumen modification with rubber, plasticizer were used to facilitate the process of rubber devulcanization. For the comparable analysis, an additive of plant origin and conventional plasticizer were used.

In order to optimize the modification process, 10 variants of the asphalt rubber production were designed and analyzed.

The initial modification was carried out in three stages, taking into account the initial low-speed mixing, shear (homogenization with cutting head) and maturation in the low-speed mixing mode. In the first stage of the modification process (low-speed mixing), additives were applied into the hot binder. In the second modification stage (shear, homogenization) fragmentation of the rubber particles using a homogenizer was carried out. The third stage (asphalt rubber maturation) comprises of binder heating at a modification temperature and slow stirring. This stage simulates the storage of the binder in the process tank with circular loop, during which rubber devulcanization and swelling processes are continued. The goal was that due to the economic aspect, the total modification time should not exceed 60 minutes.

The analysis of the results of bitumen modification with rubber, taking into account the three different stages of the binder modification, made possible the optimal choice of asphalt rubber production (Table 1).

***Table 1**. Optimal conditions for bitumen modification with rubber*

Modification stage		Total modification time
I	II	
Shearing (homogenization) at 4000 RPM with cutting head to get particles 25-50 microns	Maturation on the low-speed mixing (circulation) at 200 RPM	
[minutes]	[minutes]	minutes
30	30	60

A set of 60 types of asphalt rubber binders were tested to determine their basic and rheological properties. Asphalt rubbers were different by type of bitumen (50/70 or 70/100), crumb rubber content (15 or 18% m/m), kind of rubber modifier

(G1 to G5), content of plasticizer (0% and 2% m / m) and plsticizer type (QT or OR).

It was found that four modified binders demonstrate the most advantageous properties. Composition of those bitumen is shown in Table 2.

Table 2. *Symbols and modification diagram for selected asphalt rubber*

Sample mark	Output bitumen		Rubber content [%]	Rubber modifier type		Plasticizer content [%]		Plasticizer type	
	50/70	70/100	15	G1	G5	0%	2%	QT	OR
AR_1	X		X	X			X		X
AR_2		X	X	X		X			
AR_3		X	X	X			X	X	
AR_4		X	X		X	X			

Selected rubber modified bitumen have similar properties to comparative reference binders (polymer modified bitumen) taking into account both basic research (consistency) and rheological properties (viscosity, the m parameter, the creep stiffness S and complex modulus G*).

3.2. Comparative analysis of basic and rheological properties of selected asphalt rubber binders vs. polymer modified bitumen

Asphalt rubber binders were tested to determine their basic and rheological properties to the same extent as used for the assessment of road bitumen and polymer modified bitumen. Comparative analysis of results was carried out taking into account the rheological properties of binders before aging and after technological aging (RTFOT) as well as after operating aging (RTFOT + PAV). Some of the three most characteristic properties of modified binders are presented below: consistency, low temperature properties and complex modulus.

3.2.1. Bitumen consistency

Consistency of the tested bitumen at intermediate operating temperatures was determined by means of penetration tests while the consistency of bitumen at high operational temperatures was determined by softening point test method (Ring and Ball). Figure 1 shows the results of the penetration of the bituminous binders at 25° C, before aging, after RTFOT aging and after RTFOT + PAV aging.

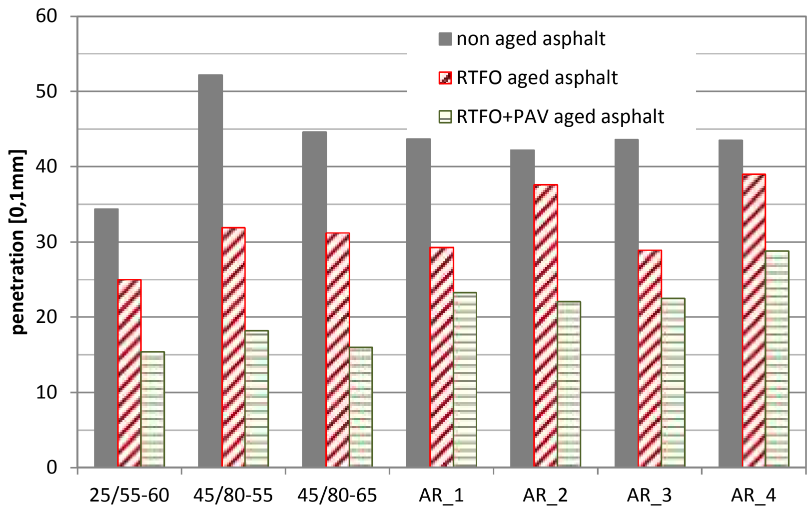

Figure 1. *Penetration of asphalt rubber and polymer modified bitumen at 25 °C*

Based on the results shown in Figure 1, it can be stated that the penetration results of asphalt rubber meet the requirements for consistency for polymer modified bitumen 25/55 and are close consistency for polymer modified bitumen 45/80.

Test results of the softening point (by Ring and Ball test method) for different binders are shown in Figure 2.

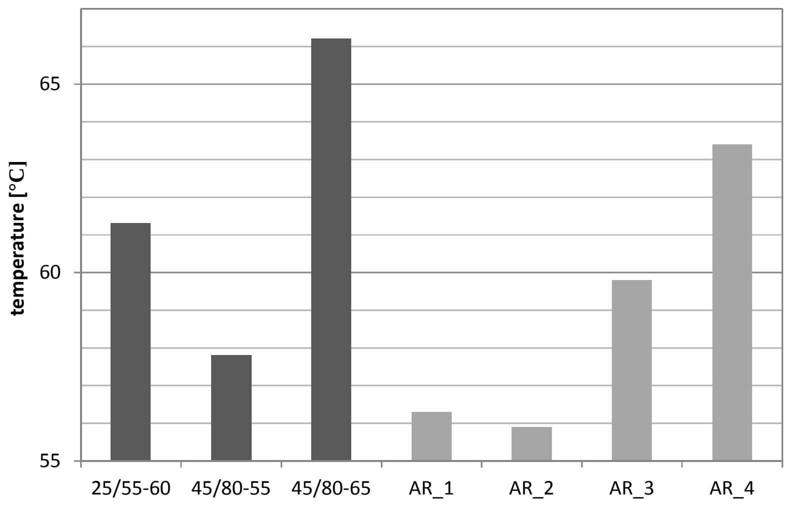

Figure 2. *Softening point by R&B test of asphalt rubber and polymer modified bitumen*

According to Figure 2, asphalt rubbers demonstrate a softening point of 56 to 63°C so they can be compared with the 45/80-55 and 25/55-60 polymer modified bitumen. AR_4 has the highest softening point and the lowest increase in softening temperature after aging.

3.2.2. Low-temperature properties of bitumen

Results of the breaking point obtained by the Fraass method for asphalt rubber and polymer modified bitumen are presented in Figure 3.

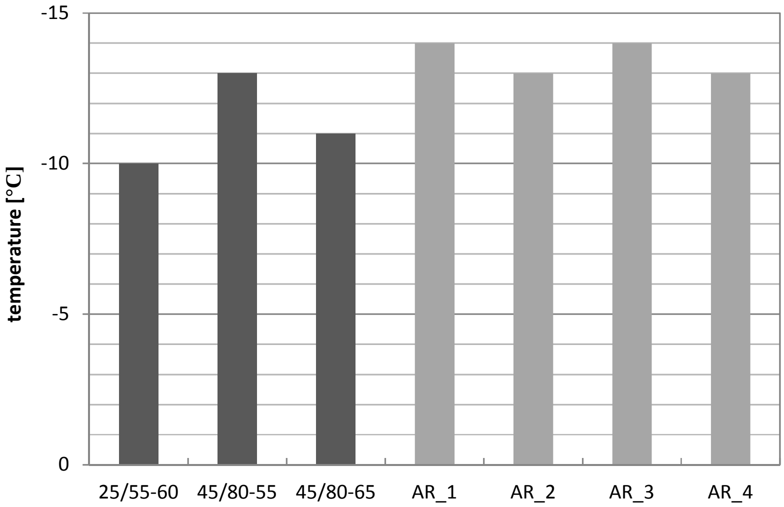

Figure 3. *The Fraass breaking point of asphalt rubber and polymer modified bitumen*

Based on the results presented in Figure 3, it can be stated that all the asphalt rubbers shown better lower breaking temperature than comparative polymer modified bitumen. This phenomenon is caused by the plastic properties of the rubber additive, more noticeable in low operational temperature.

Based on the results of the Fraass breaking point and R&B softening temperature, the temperature plasticity range can be determined. It allows assessing the preferred operating temperature range of binders used for pavement layers. The results of calculation of the temperature plasticity range are shown in Figure 4.

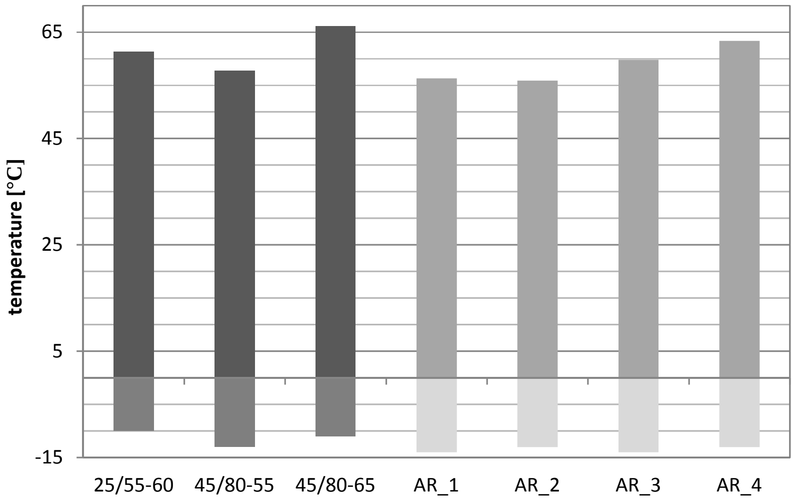

Figure 4. *Temperature plasticity range of asphalt rubber and polymer modified bitumen.*

Based on the analysis of Figure 4, it can be noticed that the asphalt rubber and polymer modified bitumen shows a wide range of ductility in temperature range above 70°C.

3.2.3. The complex modulus and phase angle

Selected test results of the complex modulus as a function of temperature for the asphalt rubber and polymer modified bitumen are shown in Figure 5. This graph indicate that the asphalt rubbers have more favorable elasticity modulus at both high and low service temperature as compared with polymer modified bitumen. Asphalt rubber binders have higher values of G* modulus at high temperatures and lower operating G* modulus at low temperatures. That indicates their lower stiffness.

Figure 6 presents plot of changes in phase angle as a function of temperature for the tested bitumen binders. Based on presented results in this graph can be concluded that asphalt rubber display better properties as compared to polymer modified bitumen. At low temperatures, asphalt rubber binders are less stiff (higher value of the tangent of phase angle) and at high temperatures (about 80°C) binder do not exhibit Newtonian fluid properties. It can be concluded that the tested asphalt rubber, in a temperature range from -20°C to 80°C retain beneficial viscoelastic properties.

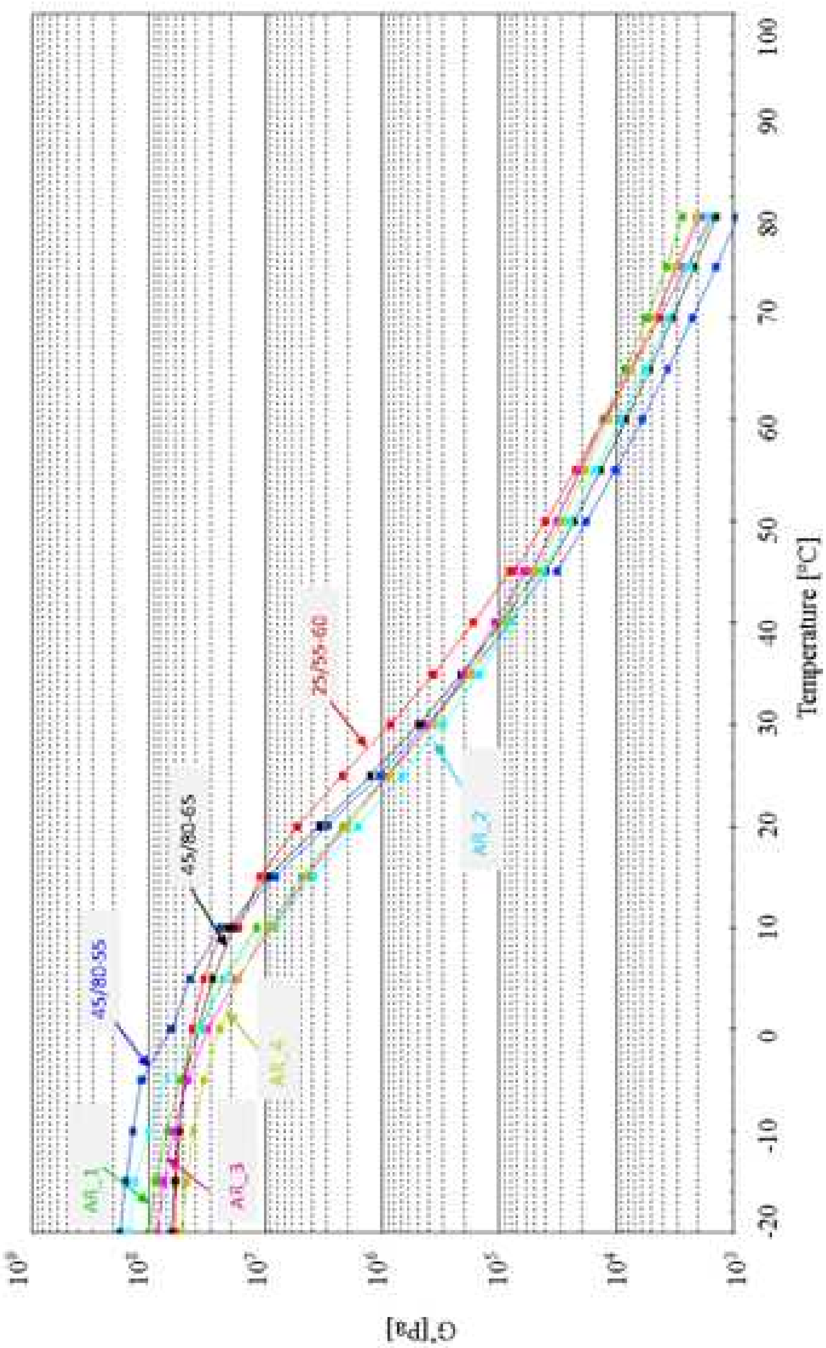

Figure 5. Stiffness modulus as function of temperature for non aged asphalt rubber and polymer modified bitumen

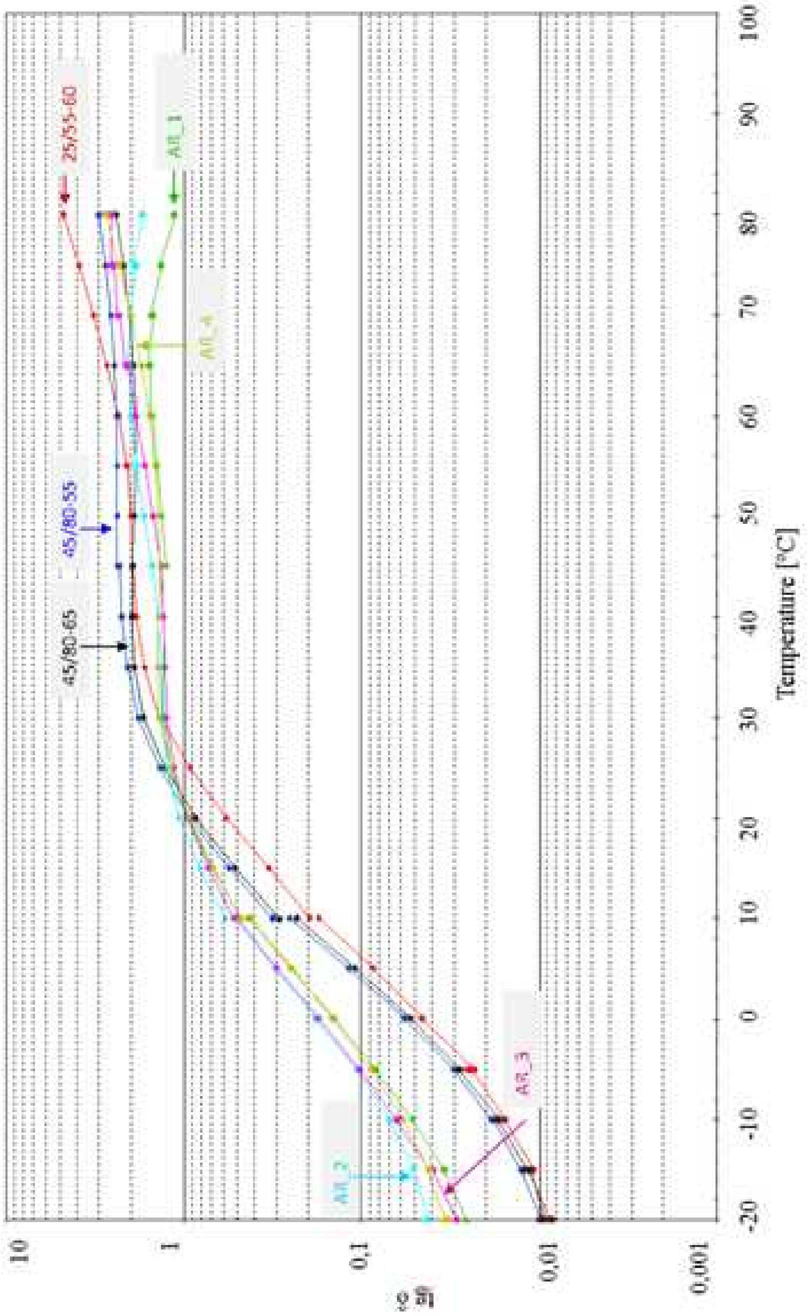

Figure 6. Tangent of the phase angle of bitumen as a function of temperature for non aged asphalt rubber and polymer modified bitumen

4. Conclusions

Asphalt rubber in Polish conditions is an innovative and environmentally friendly technology, meeting the high technical requirements. The specific conclusions from this study are as follows:

1. Obtained asphalt rubbers presents positive, wide temperature plasticity range, comparable to polymer modified bitumen.

2. The test results of the low-temperature properties and consistency of asphalt rubber in medium and high operating temperature showed that the asphalt rubber has properties comparable to polymer modified bitumen.

3. Results of rheological properties tests, i.e. G* modulus and the tangent of the phase angle (tg δ) showed, that the asphalt rubber have better viscoelastic properties as compared to polymer modified bitumen.

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