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Laboratory and Field Investigations of Polymer and Crumb Rubber Modified Bitumen

Jan B. Król[1], Piotr Radziszewski[1], Karol J. Kowalski[1], Michał Sarnowski[1] and Paweł Czajkowski[2]

1. Faculty of Civil Engineering, Warsaw University of Technology, Warsaw 00-637, Poland

2. Development and Technology Office, LOTOS Asfalt Sp. z o.o., Gdańsk 80-718, Poland

Abstract: In this paper, properties of new kind of modified bitumen are presented. Bituminous binder was modified with mix modification using polymer and additive of crumb rubber. Terminal blend process at the refinery was applied to produce the mixed modified binder. Laboratory tests were focused on the characterization of the properties of 45/80-55 CR binder with comparison to reference 50/70 and conventional polymer modified 45/80-55 bitumen. Based on conventional binder tests such as penetration, softening point and Fraass breaking point as well as BBR (bending beam rheometer) and DSR (dynamic shear rheometer) tests, rheological properties were investigated. For determination of stability of the polymer and crumb rubber, modified bitumen tube testing method was used. Based on the results analysis, improvement of the viscoelastic properties of polymer and crumb rubber modified bitumen was observed. Conventional properties and stability tests showed that it is possible to pass standard requirements for polymer modified bitumen. Mixed modification and terminal blend allow to use crumb rubber as a modifier with elimination of the separation of crumb rubber during transportation and storage at high temperature. In this paper, experience from filed sections with use of the asphalt mixture with new kind of modified bitumen is presented.

Key words: Polymer modified bitumen, crumb rubber, terminal blend.

1. Introduction

Improvement of the bituminous binder properties by the modification enhances asphalt mixture performance, especially resistance to permanent deformation, fatigue and thermal cracking [1, 2]. Together with a typically used polymer modification (SBS (styrene-butadiene-styrene)—copolymer), it is also possible to use crumb rubbers from wasted vehicle tires for binder modification [3-5]. Although technical effects of rubber modification of binders are superior, this technology has serious limitations such as low stability of bitumen-rubber during storing after production, the need of providing 10-15 °C higher technological temperatures during construction and problems with application of some of the conventional test methods to asses quality of the binder [5-7].

Crumb rubber obtained during processing of the used car tires can be used for the bitumen modification in “wet process” or added to the asphalt mixture in “dry process”, as substitution of some aggregate blend fraction. Dry process technology is simpler, however, it does not take advantage of beneficial rubber properties, such as ability to improve viscoelastic properties of bitumen [3, 8]. Wet process technology, in which good properties of rubber are utilizing in higher rate, is more complex to be applied in industrial scale and requires the use of special equipment to modify binder [9]. Crumb rubber is added to binder in temperature of 180 °C, then the rubber partially dissolves, swells and devulcanizes causing bitumen modification [10]. In the wet process, 5%-25% (by weight) of crumb rubber is modified to bitumen. Application of the crumb rubber modified bitumen produced in wet technology causes improvement of the viscoelastic properties of the asphalt mixture and is more justified by the technical and economic aspects than dry process [3, 5, 8].

Corresponding author: Jan B. Król, Ph.D., research fields: road materials and pavement technology. E-mail: j.krol@il.pw.edu.pl.

Refinery production of the crumb rubber modified bitumen is also possible [11]. In such an operation, there is a need to eliminate thermo stability problem. Application of the finest crumb rubber is one of the solutions, as well as reduction of the rubber content together with addition of traditional SBS polymers in order to compensate reduced amount of rubber [12]. This technological process is commonly called "terminal blend" [8] and can be classified as a mix rubber-polymer technology, merging benefits from traditional polymer as well as crumb rubber modifications allowing to reduce amount of the polymers added [12].

2. Materials and Testing Method

One polymer-rubber modified bitumen 45/80-55 CR (crumb rubber) and two reference conventional binders (one polymer modified bitumen 45/80-55 and one unmodified bitumen 50/70) were used in this study. Two reference bitumens are typical binders used in Polish market for the pavement friction coarse. Polymer-rubber modified bitumen is a new kind of binder which is obtained by mixed modification with copolymer SBS and crumb rubber from tires in an amount of not more than 10% of mass. Terminal blend process at the refinery was applied to produce the mixed modified binder. Apart from the traditional "wet process" which is used for production of ready-to-use asphalt rubber, a new kind of mixed modification method (polymer-rubber) allows storage and hulling CR binder similarly to the traditional SBS binder. Mixed modification has been allowed to reduce of the polymer content of SBS in bitumen up to 50% of mass. The aim of this investigation was to obtain binder with similar properties in comparison to reference polymer modified bitumen. The conventional properties of bitumens used in this study are shown in Table 1.

The original and RTFOT (rolling thin film oven test) aged bitumen and modified bitumen were tested for R & B (ring and ball) softening point, penetration and Fraass breaking point according to the standard procedure as described in the European Standards. Based on the penetration at 25 °C and R & B softening point temperature, penetration index was calculated (EN 12591:2009, Annex A). Plasticity range was calculated as a temperature range between Fraass breaking temperature and R & B softening point temperature. Dynamic viscosity was measured according to ASTM (American Society for Testing and Materials) D 4402 (Standard Test Method for Viscosity Determination of Asphalt at Elevated Temperatures Using a Rotational Viscometer) in the rotating spindle apparatus with a temperature range from 60 °C to 150 °C. The viscosity was measured with temperature increasing from 60 °C up to 150 °C.

Table 1 Conventional (standard) properties of tested bitumen.

Properties	50/70	45/80-55	45/80-55 CR
Penetration at 25 °C (0.1 mm)	58	49	46
Softening point by R & B (°C)	50	60.6	62.2
Force ductility at 5 °C (J/cm^2)	Fracture	8.3	7.8
Flash point (°C)	367	> 235	> 235
Fraass breaking temperature (°C)	-12	-15	-16
Elastic recovery at 25 °C (%)	6	74	72
Plasticity range (°C)	62	76	78
Penetration index	-0.9	1.1	1.2
Stability—difference in R & B (°C)	-	1.2	1.2
Chang of mass (%)	0.13	0.06	0.09
Retained penetration at 25 °C after RTFOT (%)	67	68	67
Increase in softening point by R & B after RTFOT (°C)	4.4	6.6	7.6
Elastic recovery at 25 °C after RTFOT (%)	5	69	68

BBR (bending beam rheometer) and DSR (dynamic shear rheometer) were used to determine rheological properties of tested bitumens. Black curve diagram and plots of stiffness modulus isotherms were analyzed for determination of the rheological behavior of tested binders. For determination of stability of the polymer and crumb rubber, modified bitumen tube testing method was used.

3. Rheological and Technical Behavior of Binder

Tested bitumens were characterized with a similar properties as described in European Standard. As it is shown in Table 1, unmodified bitumen is a little softer than the modified bitumen at ambient temperature (shown by penetration) and modified bitumen present over 10 °C higher softening point temperature. Both modified bitumens have lower Fraass breaking point temperature than unmodified binder. Modified binders have wider plasticity range (up 76-78 °C) while for unmodified bitumen this value is equal to 62 °C. Elastic recovery for polymer modified bitumen as well as for the polymer-rubber modified bitumen are typical as for the elastomeric modified bitumen (over 70%).

Analysis of dynamic viscosity curves has shown different viscosity characteristic at wide range of temperature for all tested bitumens. Polymer-rubber modified bitumen (CR) at high service temperature (60 °C) has indicated three times higher viscosity than other binders (Fig. 1).

Polymer-rubber modified bitumen has also demonstrated higher viscosity susceptibility which means that viscosity should faster decrease with the same temperature range that for the neat bitumen. This phenomenon is really advantageous from hot mix asphalt production point of view. The dynamic viscosity of both modified bitumens (PMB—polymer modified bitumen, CR—crumb rubber) has demonstrated similar viscosity level of 0.5 ÷ 0.6 Pa·s at 150 °C and the same viscosity level of 0.2 Pa·s at 165 °C.

Low temperature properties were characterized by Fraass breaking temperature and flexural creep stiffness from BBR rheometer. Comparison of stiffness modulus isotherms for original and modified binders at low temperature was presented in Fig. 2. It can be noticed that stiffness modulus increases with lowering temperature.

All binders at -6 °C presented similar value of

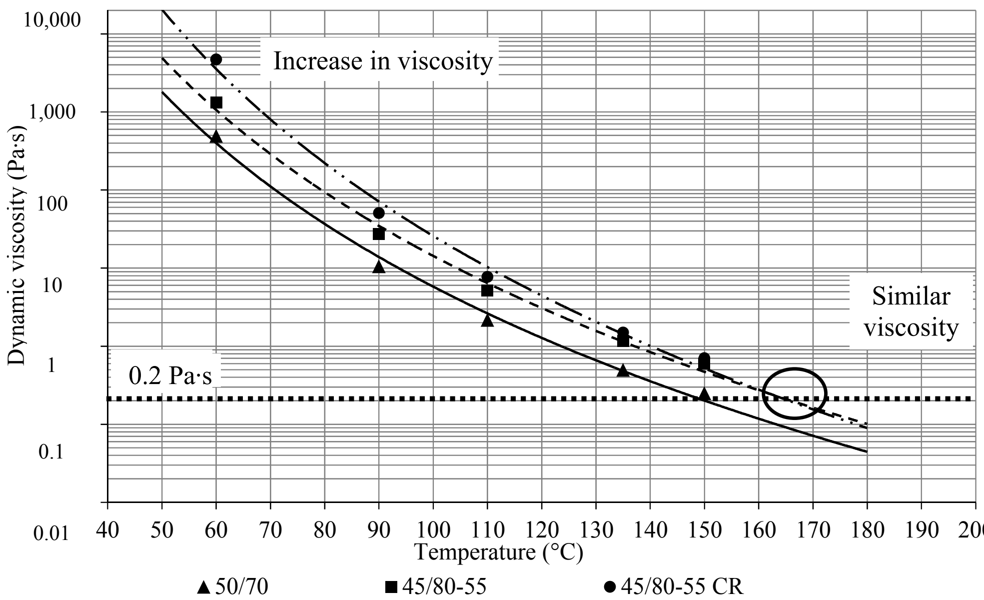

Fig. 1 Dynamic viscosity vs. temperature.

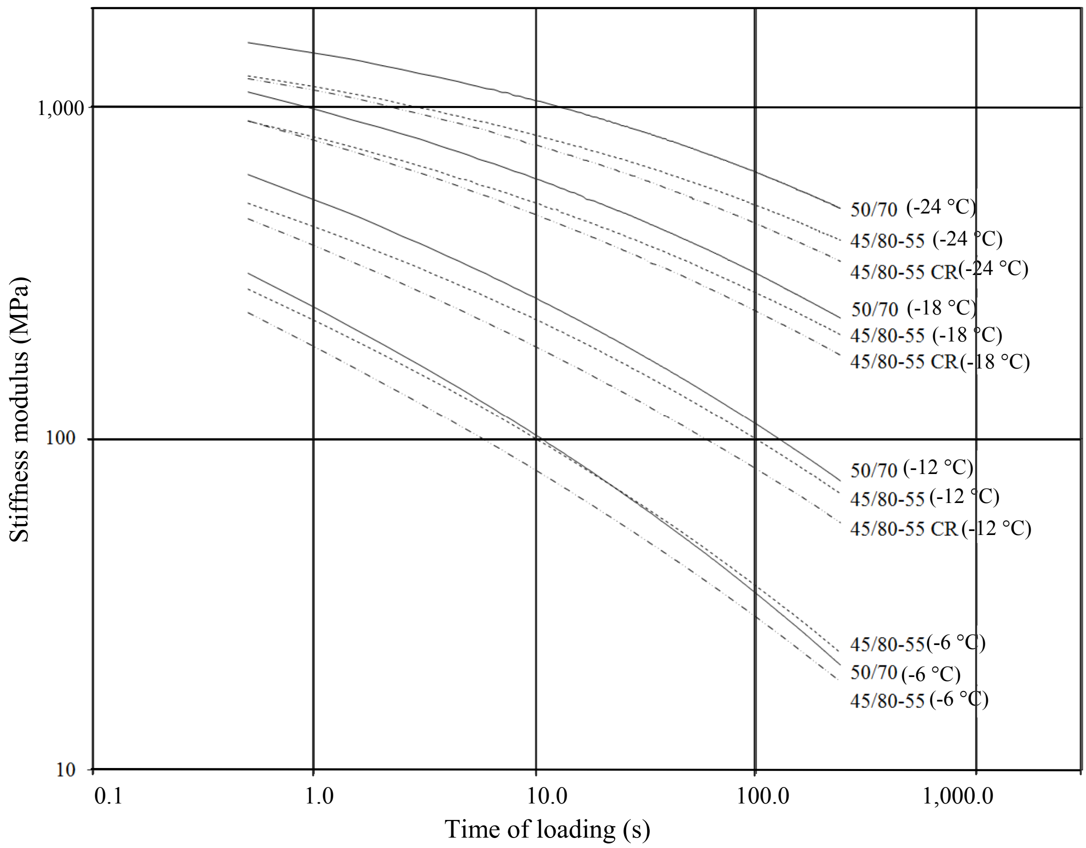

Fig. 2 Stiffness modulus isotherms vs. time loading for non-aged binders at low temperature.

stiffness modulus but isotherm of 50/70 bitumen is more tilted due to more flexible than modified bitumen. Wider variety of properties for tested binders can be seen at -24 °C with higher value of stiffness modulus for 50/70 bitumen and good low stiffness of polymer-rubber modified bitumen (CR).

In Fig. 2, it can be observed that higher stiffness isotherm slope for polymer-rubber modified bitumen is similar with stiffness isotherm slope for unmodified binder (50/70). This good phenomena at low temperature is caused by the fact that the CR binder was modified with both polymer and rubber and, in turns, is more flexible. Higher flexibility on long time loading is affected by the lower polymer content and lower stiffness obtained due to the crumb rubber addition.

In order to better understand interaction between polymer, crumb rubber and bitumen, black curve was plotted on Fig. 3. It is well known that tg δ drives to infinity for viscous materials and tg δ equals zero for elastic materials. Bitumen as a viscoelastic material should be characterized by both of that properties in regards to the loading conditions (temperature, loading value and time). Black curve shows in wide range of temperature susceptibility of bituminous binders for changes of the complex modulus and phase angle.

Based on black curve as shown in Fig. 3 for 50/70 bitumen, it can be drawn that complex modulus "*G**" decreases with increasing phase angle value. It signifies that 50/70 bitumen constantly goes to viscous state and it is proportional to the temperature increment. Different properties can be observed for modified binder, especially below 1 kPa of complex modulus. Below that complex modulus level, phase angle does not change which means that binders (PMB and CR) represent constant viscoelastic properties instead of increasing temperature. Polymer-rubber modified bitumen (CR) demonstrates wider viscoelastic range than the polymer modified bitumen.

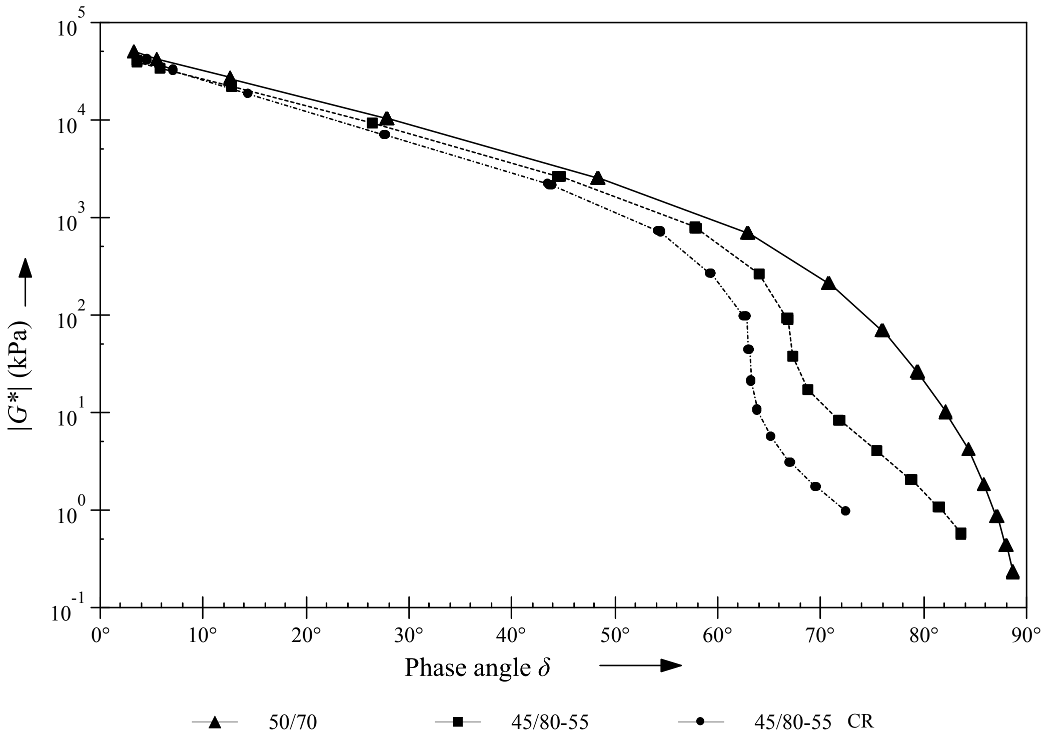

Fig. 3 Black curve for non-aged binders.

4. Thermo-Stability of Modified Bitumen

High level of thermo-stability and colloidal stability are the most important properties of polymer and crumb rubber modified bitumen. For PMB and CR binder, tube test in accordance to EN 13399:2009 was conducted. Tubes were conditioned at 180 °C for 3 days and then softening point temperature tests were conducted for top and bottom parts of the tube, difference in R & B temperature was calculated. The results have shown (Table 1) that colloidal stability of polymer-rubber modified bitumen (difference in R & B equals to 1.2 °C) is comparable to value obtained for the traditional polymer modified bitumen.

Extended stability analysis for polymer-rubber modified bitumen was conducted using the cylinder test method developed by Warsaw University of Technology. In order to determine stability of the bitumen rubber-polymer mixture, binder was heated in five litters cylinder at 180 °C for 10 days. Cylinder was equipped with upper, middle and bottom valve to collect samples from different height level. Penetration, R & B temperature, recovery elastic and microstructure in accordance to Refs. [13, 14] from UV (ultraviolet) microscope (shown in Fig. 4) were determined on start while the test was started and further at 1st, 3rd, 7th and 10th days on samples obtained from each height level.

Results show that polymer-rubber modified bitumen has stable standard properties up to 7 days of

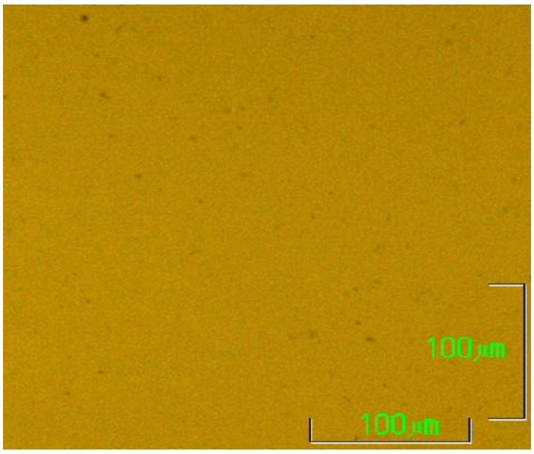

Fig. 4 Microstructure of polymer-rubber modified bitumen (CR) after 180 °C temperature conditioning measured on the bottom of cylinder after 7 days.

heating without stirring. Example of the microstructure images of the CR binder samples collected from cylinder bottom 7th day of heating are presented in Fig. 4. Microstructure assessment of all images (10 days of testing) shows that there is no difference in dispersion of polymer and rubber in bitumen in function of time.

5. Trial Sections

In 2012 in cooperation with Warsaw University of Technology, Lotos Asfalt and Skanska constructed two trial sections containing polymer-rubber modified bitumen (CR). In both cases, four centimetres of wearing course were placed as a stone mastic asphalt on the Trial Section “a” and asphalt concrete on the Trial Section “b” (Fig. 5).

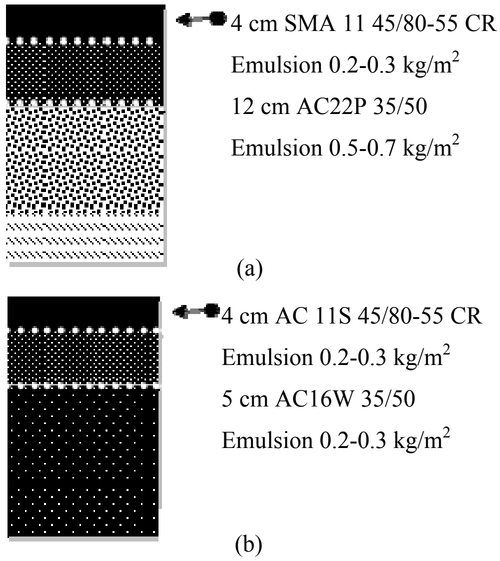

Fig. 5 Trial sections containing polymer-rubber modified bitumen 45/80-55 CR: (a) wearing coarse SMA 11; (b) wearing coarse asphalt concrete AC 11.

Trial Section “a” was located near the asphalt plant with high traffic load due to hauling aggregate and asphalt mixture for the nearest highway construction (Fig. 6). In accordance with data from 2012 year obtained from asphalt plant, on the pavement, there had been hauled 250,000 tons of asphalt mixtures. Trial Section “b” was located on the main national road number 92 between Kłodawa and Chodów citys with category of traffic load KR6 (highest in Poland). Trial Section “a” has dimension of 150 m of length and 6 m of width and Section “b” has dimension of 900 m length and 6 m of width.

Fig. 6 Trial Sections “a”, wearing coarse SMA 11 with high traffic load due to hauling aggregate and asphalt mixture.

Asphalt mixtures were designed according to the recommendations developed on the laboratory parts of the project (not presented in this paper due to the space limitation) and WT-2 requirements (WT-2 2010, asphalt pavement for national roads, asphalt mixtures, technical requirement, Polish General Directorate for National Roads and Motorways). Typical mixtures according to European Standards PN-EN 13108-5 and PN-EN 13108-1 used for Sections “a” and “b”, respectively, were modified to incorporate CR binder. During mix design process, amount of lime filler and was corrected in order to obtain correct air voids content and rutting resistance. Gradation curves of both mixtures have been lead for particles between 0.063 mm to 2 mm near the bottom control points according to WT-2. Aggregate blend was composed from the amphibolite and basalt crushed aggregate. For both mixtures, adhesive agent was used and cellulose stabiliser for SMA.

Corrections of lime filler and sand content were applied in order to improve rutting resistance. Rutting resistance was measured by small (European) and large size (LCPC—Laboratoire Central des Ponts et Chaussées) devises according to PN-EN 12697-22 at 60 °C temperature. For SMA 11 and AC 11, wheel-tracking slope (WTS_{AIR}) from small size device

Table 2 Results of asphalt mixtures with 45/80-55 CR binder applied to wearing courses of trial sections.

Properties	Value		WT-2 requirements
	SMA 11	AC 11	
Water sensitivity, ITSR (indirect tensile strength ratio) (%)	99	96	90
Rutting resistance[a] WTS_{AIR} (wheel tracking slope) (mm)/10^3 cycles, PRD_{AIR} (proportional rut depth) (%)	0.06 3.4	0.08 7.4	0.3 TBR[b]
Rutting resistance[c] PRD_{AIR} (%)	9.6	-	< 10%
Bitumen content (%)	6.2	5.4	-
Compaction factor (%)	98.1	99.8	≥ 97/≥ 98

[a]Small device, method B in air, 60 °C, 10,000 cycles;
[b]To be reported;
[c]Large device LCPC, 60 °C, 10,000 cycles.

was obtained with a value of 0.06 and 0.08 mm/1,000 cycles, respectively. Polish requirement for wheel-tracking slope for wearing courses are 0.3 mm/1,000 cycles (Table 2). In current documents, requirements for rutting resistance measured with using of the large size device are not observed, however, in previous version, 10% of proportional rut depth was required. For SMA mixture, 9.6% of proportional rut depth was occurred.

Furthermore, for mixture sampling from asphalt plant, a cylindrical specimens were compacted to determine water sensitivity. Polish requirement for water sensitivity for wearing courses is 90% with one frozen cycle and conditioning the samples before the freezing at 40 °C and after freezing at 60 °C. Testing temperature to determine water sensitivity is 25 °C. Both mixtures passed the requirement with value of 99% for SMA and 96% for AC.

It has to be noticed that after one winter season, both field sections exhibited good condition without any visible defects.

6. Conclusions

Application of the crumb rubber from the wasted car tires for the asphalt binder modification is in-line with a sustainability requirements observed in road constructions. For a long time, researchers were unable to develop thermo-stable crumb rubber modified binder which could be stored and transported similarly to the polymer modified bitumen.

As it was proved by the research conducted in this study, polymer and crumb rubber modified bitumen demonstrated wide visco-elastic range as well as good low and high temperature properties.

Experience obtained during construction and exploitation of two field sections confirmed that application of this technology does not influence HMA (hot mix asphalt) plant installations and does not impact construction process required to obtain good asphalt pavement.

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