CETRA^{2024} 15-17 May 2024, Cavtat, Croatia
8th International Conferenceon Road and Rail Infrastructure

CREEP AND RECOVERY OF SBS MODIFIED BITUMEN DEPENDING ON THE PROPERTIES OF BASE BITUMEN AND POLYMER

Judita Škulteckė, Audrius Vaitkus, Ovidijus Šernas
Vilnius Gediminas Technical University, Road Research Institute, Lithuania

Abstract

The use of polymer modified bitumen (PMB) is continuously growing due to the polymer ability to increase the asphalt pavements resistance to rutting, as well as other performance characteristics. However, in practice, asphalt pavements with the same class of PMB perform differently even though the same technical requirements are met. Previous studies have demonstrated that creep and recovery can differ more than 4 times between the same class of PMB. It is known to be influenced by the properties of both base bitumen and polymer. However, there is a lack of more detailed analysis. Therefore, the aim of this paper is to determine how the properties of both the base bitumen and the polymer affect the creep and recovery of PMB. For this purpose, three 70/100 binders, which differ in fractional composition (asphaltenes, resins, aromatics and saturates – SARA) were laboratory modified with three polymers, which differ in structure and molecular weight. Styrene-butadiene-styrene (SBS), as one of the most popular modifiers, was selected for bitumen modification. In all cases, 3% of SBS were used to produce PMB. Research showed that the properties of the base binder have a significantly higher effect on the creep and recovery of PMB compared to the properties of SBS when 3% SBS is used.

Keywords: MSCR, creep, recovery, non-recoverable creep compliance, styrene-butadiene-styrene (SBS), polymer modified bitumen (PMB)

1 Introduction

With increasing traffic loads and climate change, the use of polymer modified bitumen (PMB) is continuously increasing. PMB increases the asphalt pavements resistance to rutting, fatigue, and thermal cracking and, as a result, leads to longer durability [1–5]. Asphalt pavements with PMB are estimated to last from 5 to 10 years longer than those with unmodified bitumen [3, 6, 7]. A possible explanation for the difference in performance (durability) of asphalt pavements with PMB (5 years or 10 years longer) could be that asphalt pavements with the same class (type) of PMB perform differently even when existing requirements are met. Previous studies have shown that creep and recovery can differ more than 4 times between the same class (type) of PMB [8].

The behaviour of PMB is influenced by several factors, including the properties of the base bitumen and the characteristics of the polymer and its amount [9, 10]. The chemical composition, rheological properties, and susceptibility to ageing of the base bitumen significantly affect its interaction with the polymer and, consequently, the mechanical properties of the modified bitumen. Additionally, the type, content, and distribution of polymer within the bituminous matrix play a crucial role in improving PMB performance.

DOI: https://doi.org/10.5592/CO/CETRA.2024.1607

Extensive research has been carried out on the performance of PMB [11–14]. However, there is a lack of studies focused on the effect of properties of the base bitumen and polymer on the creep and recovery of PMB. Understanding the creep and recovery characteristics of PMB is crucial for predicting asphalt pavement performance. Creep, the gradual deformation of a material under constant stress over time, and recovery, the ability of the material to regain its original shape after stress removal, are fundamental parameters that govern the long-term behaviour and durability of asphalt pavements [15–19].
This paper aims to determine the creep and recovery of nine laboratory modified binders and relate their performance to the properties of components used for modification (neat bitumen and polymer). The data obtained will help to address the research gap on the effect of the properties of the base bitumen and polymer on the creep and recovery of PMB.

2 Materials and methods

2.1 Materials and preparation of PMBs

Three 70/100 binders, which differ in fractional composition (saturates, aromatics, resins, and asphaltenes – SARA), were laboratory modified with three different polymers. The properties of base bitumen and polymer are given in Table 1 and Table 2, respectively. Styrene-butadiene-styrene (SBS), as one of the most widely used polymers, was selected for bitumen modification. In all cases, 3% of SBS by weight was used to produce PMB.

Table 1 Properties of base bitumen 70/100

Properties	Bitumen code		
	A	B	C
Penetration [dmm] (dmm = 0.1 mm)	73.1	82.6	83.2
Softening point [°C]	49.1	46.4	45.8
SARA fractions [%]			
saturates	8.3	11.6	6.1
aromatics	33.5	27.1	33.7
resins	40.8	46.2	43.8
asphaltenes	17.4	15.1	16.4
Colloidal stability (Gaestel) index Ic [–]	0.345	0.364	0.290

Table 2 Properties of SBS polymers

Properties	SBS polymer		
	1	2	3
Structure*	linear	radial	radial
Styrene-butadiene ratio*	31/69	20/80	30/70
Molecular weight M_n [kDa]	103.9	178.0	255.2
Molecular weight M_w [kDa]	112.5	186.2	270
Polydispersity M_n/ M_w [–]	1.08	1.05	1.06
Notes: * – declared by producer			

All PMBs were produced using a high-shear Silverson L5M-A laboratory mixer with general-purpose disintegrating head. The neat bitumen was preheated according to the European standard EN 12594:2015 and then placed in the modification device, which was already preheated to 185 °C. The neat bitumen was stirred at 3000 rpm for 15 min to achieve homogeneity. After that, the SBS was gently poured into the bitumen in about 5 min and the rotation speed was increased up to 6000 rpm. After 1 hour at 6000 rpm, the modification was stopped.

2.2 Test methods

First, for all PMBs produced, penetration at 25 °C and softening point were determined according to the European standards EN 1426:2015 and EN 1427:2015. Subsequently, the creep and recovery were determined by performing the multiple stress creep and recovery (MSCR) test according to the American standard AASHTO T 350-19. The American standard instead of the European one was used to determine creep and recovery because a recently conducted interlaboratory study showed that 10 cycles of preloading at 0.1 kPa (based on the AASHTO 350) has a significant effect on MSCR results, especially for PMB [20].

In the MSCR test according to AASHTO T 350-19, 20 creep and recovery cycles are performed at 0.1 kPa, where the first ten cycles are used to preload the sample, and the last ten cycles are used to calculate the test results. After that the stress is increased to 3.2 kPa and at this stress level, ten creep and recovery cycles are performed. Each creep and recovery cycle includes a creep period with constant stress of 1 s and a recovery period with zero stress of 9 s. The MSCR test was carried out using a 25 mm geometry with a 1 mm gap at a test temperature of 60 °C. Three specimens were tested for each PMB.

3 Results and discussion

3.1 Penetration and softening point

Since all binders were laboratory modified and the polymer modified bitumen is designated based on the penetration and softening point, these two characteristics were determined to identify which type of PMB was produced. The results are given in Fig. 1. There are the average of three values. As can be seen in Fig. 1, all laboratory produced binders with 3% SBS can be assumed to be PMB 25/55-60 except C-1 and C-2. These binders had a slightly lower softening point (59.9 °C and 59.8 °C) when required (≥60 °C). The highest softening point was up to 71.5 °C (B-2). Meanwhile, the penetration varied from 29 dmm (B-2) to 40 dmm (C-3), dmm - decimillimetre, 0.1 mm.

It is apparent from Fig. 1 that the properties of PMBs at the same SBS content (3 %) depend on both the base binder and the polymer. PMBs with SBS 1 revealed a penetration of 33–35 dmm and a softening point of 59.9–68.3 °C, PMBs with SBS 2 – a penetration of 29–39 dmm and a softening point of 59.8–71.5 °C, and PMBs with SBS 3 – a penetration of 32–40 dmm and a softening point of 64.8–66.4 °C. However, the relationship between the penetration and softening point of the PMB and base binders was not determined. Therefore, PMB properties strongly depend on the chemical composition of the base binder. The more saturates are in base bitumen, the higher the softening point. The increase in the softening point depends on the properties of SBS. No other trends were observed between the fractional composition of the base binder and penetration as well as the softening point of the PMBs.

The properties of SBS affect the penetration and softening of PMBs as well. However, the effect also depends on the properties of the base binder. For example, the penetration and softening point of PMBs with base binder A (A-1, A-2, and A-3) were not affected by the properties of SBS (the penetration was 33–34 dmm and the softening point – 64.9–65.0 °C irrespective of the SBS). Meanwhile, the penetration was 29–34 dmm and 35–40 dmm and the softening point was 66.4–71.5 °C and 59.8–64.8 °C, respectively for base binder B and C depending on the properties of SBS. However, no relationship between the SBS properties and penetration as well as the softening point of the PMBs was observed.

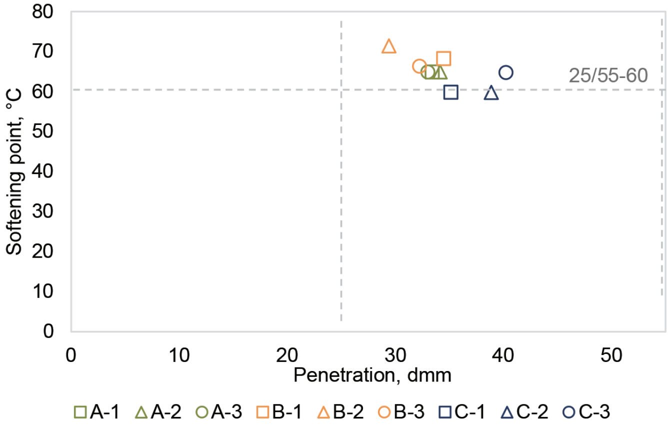

Figure 1 Penetration and softening point of laboratory modified binders

3.2 Creep and recovery

The creep and recovery of laboratory modified binders (3 base binders 70/100 and 3 different SBS) were determined by the multiple stress creep and recovery (MSCR) test. The results expressed as the relationship between the average percent recovery ($R_{3.2}$) and non-recoverable creep compliance ($J_{nr\,3.2}$) are given in Fig. 2. Each of points presents the average of three values. Overall, $R_{3.2}$ varied from 17% (C-2) to 49% (B-2) and $J_{nr\,3.2}$ – from 0.205 kPa^{-1} (B-2) to 0.907 kPa^{-1} (C-2).

As can be seen from Fig. 2, the creep and recovery of PMBs at the same SBS content (3 %) depend on both the properties of the base binder 70/100 and the polymer. Recovery and non-recoverable creep compliance at 60 °C and 3.2 kPa because of the properties of the base binder 70/100 differed up to 1.4–2.9 and 2.2–4.4 times depending on the SBS, respectively. PMBs with SBS 1 recovered 18–42% and revealed a $J_{nr\,3.2}$ of 0.211–0.766 kPa^{-1}, PMBs with SBS 2 recovered 17–49 % and revealed a $J_{nr\,3.2}$ of 0.205–0.907 kPa^{-1}, and PMBs with SBS 3 recovered 28–40 % and revealed a $J_{nr\,3.2}$ of 0.345–0.736 kPa^{-1}.

PMBs with base binder B, which had the highest amount of saturates (11.6%) at 60 °C and 3.2 kPa recovered the most (40–49%) and had the lowest $J_{nr\,3.2}$ values (0.205–0.345 kPa^{-1}). While PMBs with base binder C, which had the lowest amount of saturates (6.1%) showed the lowest recovery (17–28%) and the highest $J_{nr\,3.2}$ values (0.736–0.907 kPa^{-1}). Therefore, the more saturates are in base bitumen, the higher the recovery and the lower the non-recoverable creep compliance of modified bitumen with SBS. This finding is similar to those reported by Škulteckė et al. who analysed the effect of SARA on creep and recovery of PMBs taken from different producers at different production times [8]. In that study, the value of $R_{3.2}$ increased and the value of $J_{nr\,3.2}$ decreased as the percentage of saturates and aromatics increased in PMBs. It should be noted that in this study no other trends were observed between the fractional composition of the base binder and recovery, as well as the $J_{nr\,3.2}$ of the PMBs.

The properties of SBS affect the creep and recovery of PMBs as well. However, this effect is lower compared with the properties of base binder. The recovery and non-recoverable creep compliance at 60 °C and 3.2 kPa because of the properties of SBS differed up to 1.2–1.7 times depending on the properties of the base binder 70/100. However, no relationship was observed between the SBS properties and the values of $R_{3.2}$ and $J_{nr\,3.2}$ of the PMBs.

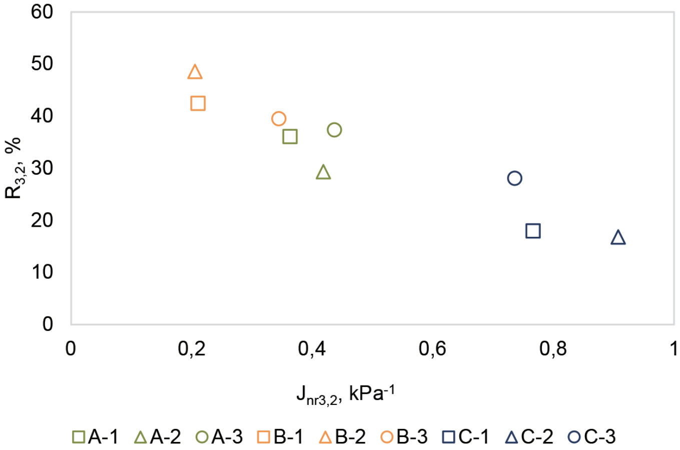

Figure 2 Average percent recovery ($R_{3.2}$) vs non-recoverable creep compliance ($J_{nr\,3.2}$)

4 Conclusions

This research presents the effect of the properties of the base bitumen 70/100 and SBS (structure, molecular weight, etc.) on the creep and recovery of laboratory modified binders. Three 70/100 binders, which differ in penetration, softening point, and fractional composition, were laboratory modified with three different polymers using 3% SBS (overall 9 PMBs were produced and tested). To identify which type of PMB was produced, the penetration and softening point were also determined. Based upon the results obtained in this research, the following conclusions are drawn:

- PMB 25/55-60 can be successfully produced by mixing bitumen 70/100 with 3% SBS. However, in all cases the physical, mechanical, and chemical properties of base binder as well as the properties of SBS have to be considered individually. For example, bitumen 70/100 (penetration – 83 dmm, softening point – 45.8 °C) modified with 3% SBS, which molecular weight was 113–186 kDa, revealed a slightly lower softening point (around 59 °C) when required one (≥60 °C). However, when SBS with molecular weight of 270 kDa was used to modify the same base binder, the softening point increased to 64.8 °C.
- The performance of produced PMBs with base binder A (penetration – 73 dmm, softening point – 49.1 °C, saturates – 8.3%, aromatics – 33.5%, resins – 40.8% and asphaltenes – 17.4%) was not affected by the properties of SBS. The penetration of PMBs was 33–34 dmm and the softening point – 64.9–65.0 °C However, this was not the case for PMBs with the other two base binders B and C, which penetration – 83 dmm, softening point – 45.8–46.4°C, saturates – 6.1–11.6%, aromatics – 27.1–33.7%, resins – 43.8–46.2% and asphaltenes – 15.1–16.4%. This trend was not observed when creep and recovery were analysed. Further studies are needed to identify what causes if SBS properties have an effect on PMB performance or not.

- The creep ($J_{nr\,3.2}$) and recovery ($R_{3.2}$) among PMBs can differ more than two times even when the same type of base binder (e.g., 70/100) and the same amount of SBS (e.g., 3%) are used. What is interesting is that the difference in properties is more influenced by the properties of base bitumen compared to the properties of SBS ($J_{nr\,3.2}$ differed up to 2.1–4.4 times and $R_{3.2}$ – up to 1.4–2.9 times depending on the properties of base bitumen while $J_{nr\,3.2}$ and $R_{3.2}$ differed up to 1.2–1.7 times depending on the properties of SBS).
- The more saturates are in base bitumen, the higher the softening point and recovery of PMBs, and the lower the non-recoverable creep compliance of PMBs. PMBs produced with base bitumen 70/100 (penetration – 83 dmm, softening point – 46.4 °C), which had the highest amount of saturates (11.6%), had the softening point of 66.4–71.5 °C, $R_{3.2}$ value of 40–49% and $J_{nr\,3.2}$ value of 0.205–0.345 kPa^{-1} depending on the properties of SBS. While PMBs produced with base bitumen 70/100 (penetration – 83 dmm, softening point – 45.8 °C), which had the lowest amount of saturates (6.1%), had the softening point of 59.8–64.8 °C, $R_{3.2}$ value of 17%–28% and $J_{nr\,3.2}$ value of 0.736–0.907 kPa^{-1} depending on the properties of SBS.
- The properties of SBS have an effect on the performance of PMBs, however, no relationship was established between the structure of SBS (linear vs radial) or the molecular weight (113–270 kDa) and the values of $R_{3.2}$ and $J_{nr\,3.2}$ of PMBs with 3% SBS. Additional research is needed to better understand the interaction between base bitumen and SBS, the formation of a polymer network within bitumen, and its effect on PMB performance.

Acknowledgments

This research has received funding from the Research Council of Lithuania (LMTLT), agreement No. S-MIP-23-106.

References

[1] Lu, X., Isacsson, U., Ekblad, J.: Low-temperature properties of styrene–butadiene–styrene polymer modified bitumens, Construction and Building Materials, 12 (1998), pp. 405–414, DOI: 10.1016/S0950-0618(98)00032-4

[2] Soleymani, H.R., Zhai, H., Bahia, H.: Role of Modified Binders in Rheology and Damage Resistance Behavior of Asphalt Mixtures, Transportation Research Record: Journal of the Transportation Research Board, 1875 (2004), pp. 70–79, DOI: 10.3141/1875-08

[3] Von Quintus, H.L., Mallela, J., Buncher, M.: Quantification of Effect of Polymer-Modified Asphalt on Flexible Pavement Performance, Transportation Research Record: Journal of the Transportation Research Board, 2001 (2007), pp. 141–154, DOI: 10.3141/2001-16

[4] Zhu, J., Birgisson, B., Kringos, N.: Polymer modification of bitumen: Advances and challenges, European Polymer Journal, 54 (2014) 1, pp. 18–38, DOI: 10.1016/j.eurpolymj.2014.02.005

[5] Ahmed, A.W., Said, S.F., Lu, X., Carlsson, H.: Pavement performance follow-up and evaluation of polymer-modified test sections, International Journal of Pavement Engineering, 20 (2019), pp. 1474–1487, DOI: 10.1080/10298436.2018.1435878

[6] Lu, X., Said, S., Soenen, H., Ahmed, A., Carlsson, H.: Long lasting asphalt pavements with polymer modified bitumens, 7th Eurasphalt Eurobitume Congr, pp. 1–10, Madrid, Spain, 15-17 June 2021.

[7] Lu, X., Soenen, H., Heyrman, S., Redelius, P.: Durability of Polymer Modified Binders in Asphalt Pavements, XXVII Int. Balt. Road Conf., pp. 1–10, Vilnius, Lithuania, 2013.

[8] Škulteckė, J., Vaitkus, A., Šernas, O., Liubinas, K.: Analysis of variation in creep and recovery of polymer modified bitumen used for asphalt mixtures production of various producers, 8th E&E Congr., Budapest, Hungary, 19-21 June 2024.

[9] Bulatović, V.O., Rek, V., Marković, K.J.: Influence of polymer types on bitumen engineering properties, Materials Research Innovations, 17 (2013), pp. 189–194, DOI: 10.1179/1433075X12Y.0000000059

[10] Behnood, A., Olek, J.: Stress-dependent behavior and rutting resistance of modified asphalt binders: An MSCR approach, Construction and Building Materials, 157 (2017), pp. 635–646, DOI: 10.1016/j.conbuildmat.2017.09.138

[11] Lu, X., Isacsson, U.: Compatibility and storage stability of styrene-butadiene-styrene copolymer modified bitumens, Materials and Structures, 30 (1997), pp. 618–626, DOI: 10.1007/bf02486904

[12] Vaitkus, A., Paliukaitė, M.: Evaluation of Time Loading Influence on Asphalt Pavement Rutting, Procedia Eng, 57 (2013), pp. 1205–1212, DOI: 10.1016/j.proeng.2013.04.152

[13] Gražulytė, J., Vaitkus, A., Kravcovas, I.: Bitumen selection approach assessing its resistance to Low temperature cracking, 4rd International Conference on Road and Rail Infrastructures, pp. 643–649, Šibenik, Croatia, 23–25 May 2016.

[14] Zhou, S., Wang, J., Li, S., Yan, C.: Investigating the rheological behaviour of styrene–butadiene–styrene modified asphalt, Road Materials and Pavement Design, pp 1–16, 2023, DOI: 10.1080/14680629.2023.2287715

[15] D'Angelo, J.A.: The Relationship of the MSCR Test to Rutting, Road Materials and Pavement Design, 10 (2009), pp. 61–80, DOI: 10.3166/rmpd.10HS.61-80

[16] Zhang, K., Walubita, L.F., Faruk, A.N.M., Karki, P., Simate, G.S.: Use of the MSCR test to characterize the asphalt binder properties relative to HMA rutting performance – A laboratory study, Construction and Building Materials, 94 (2015), pp. 218–227, DOI: 10.1016/j.conbuildmat.2015.06.044

[17] Laukkanen, O.V., Soenen, H., Pellinen, T., Heyrman, S., Lemoine, G.: Creep-recovery behavior of bituminous binders and its relation to asphalt mixture rutting, Materials and Structures, 48 (2015), pp. 4039–4053, DOI: 10.1617/s11527-014-0464-7

[18] Salim, R., Gundla, A., Underwood, B.S., Kaloush, K.E.: Effect of MSCR Percent Recovery on Performance of Polymer Modified Asphalt Mixtures, Transportation Research Record: Journal of the Transportation Research Board, 2673 (2019), pp. 308–319, DOI: 10.1177/0361198119841283

[19] Skronka, G., Blascik, M., Vacin, O., Jasso, M.: Impact of shear stress levels on validity of MSCR tests, Road Materials and Pavement Design, 24 (2023) 1, pp. 1820–1836, DOI: 10.1080/14680629.2022.2106293

[20] Wang, D., Zhu, J., Porot, L., Cannone Falchetto, A., Damen, S.: Multiple stress creep and recovery test for bituminous binders – influence of several key experimental parameters, Road Materials and Pavement Design, 24 (2023), pp. 290–308, DOI: 10.1080/14680629.2023.2180992