

Field Performance of Polymer Modified Bitumen

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Abstract

This review comprehensively examines the field performance of polymer modified bitumen (PMB) in road and bridge applications, with a focus on trials and testing conducted over the past 30 years, particularly in the Nordic countries. The report highlights both the positive and negative outcomes observed in various case studies, including long-term field trials in Sweden and Norway, as well as bridge applications such as the High Coast and Öresund bridges. Laboratory and field data consistently demonstrate that PMB enhances asphalt durability, rutting resistance, fatigue life, and resistance to cracking and aging compared to conventional bitumen. Statistical analyses of extensive road network data further confirm that the use of PMB extends pavement service life and reduces maintenance needs. However, the review also notes that the degree of improvement depends on factors such as polymer type, binder composition, mix and pavement design, and workmanship. The findings underscore the importance of proper material selection and quality control to fully realise the benefits of using PMB in sustainable road infrastructures.

Keywords: Polymer modified bitumen, Asphalt performance, Field trials, Durability, Aging, Rutting, Fatigue, Cracking

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1. Introduction

In developing sustainable road infrastructures, asphalt pavements are required to have better performance and longer lifetime under toughly changed environmental conditions and increased traffic densities and axle loading than in the past. At the same time, there is pressure on reducing initial material costs. To ensure pavement long-term durability, thus minimising maintenance needs and conserving resources, proper selection of paving materials along with optimal mix and pavement design are of great importance.

Basically, bituminous binders should be designed to resist different types of pavement failure (e.g. rutting, cracking, and water damage) by desired properties over a wide range of climate and traffic conditions. This is however not always possible with conventional bitumen, leading to development and use of polymer modified bitumen (PMB).



PMB can be defined as a bituminous binder obtained by incorporation of polymer into bitumen using mechanical mixing and/or chemical reaction. The formation of PMB with improved properties is greatly dependent on polymer characteristics and content, bitumen composition, as well as mixing (production) process. The polymers used for bitumen modification can be classified into two broad categories: plastomers and elastomers. Typical elastomers include styrene-butadiene-styrene (SBS) block copolymer, styrene-ethylene-butylene-styrene (SEBS) and styrene-butadiene-rubber (SBR), and typical plastomers include polyethylene (PE), polypropylene (PP), ethylene vinyl acetate (EVA), and ethylene-butyl acrylate (EBA) copolymers. Among all polymer modifiers for bitumen, SBS types are most used, thanks to their combining elastic and thermoplastic properties (Casola, 2005; Isacsson and Lu, 1995; Lewandowski, 1994; Zhu et al., 2014).

In literature, there are great number of investigations published on PMBs, and positive performance has been commonly recognised and demonstrated by various laboratory tests on binders and asphalt mixes. The improved properties are normally shown on long-term durability (resistance to aging) (Ruan et al., 2003; Yu et al., 2011), resistance to permanent deformation (Elseifi et al., 2003; Sirin et al., 2008), resistance to wear (Blomberg, 1988), resistance to fatigue (Ahmed et al., 2019; Newman, 2004), resistance to low temperature cracking (Isacsson and Zeng, 1998; King et al., 1993), and resistance to moisture damage (Awanti et al., 2008; Timm et al., 2013). On the other hand, documentation of improved field performance for PMBs is still limited.

The main objective of this report is to collect and review relevant field data on PMBs, especially regarding case studies in Nordic countries. Statistical studies are also reviewed, highlighting application outcomes and benefits of PMBs.

2. Field performance - general overview

Admixture of polymer to bituminous binders intended for road application can be tracked back as early as 1823 (Isacsson and Lu, 1995), but real field trials were much later in the 1930s (Lewandowski, 1994). The general experience of using PMBs, especially in Europe, was very positive (Terrel and Walter, 1986). In Table 1, typical field trials carried out in Europe and North America are summarised. From Table 1, one can see that six of the ten investigations listed show improvement in rutting and/or cracking resistance for PMBs, and in two other investigations (Bottin, 1992; Elmore et al., 1993) no significant difference was observed between PMB and control sections. It should be noticed that for the two mentioned cases of no significant difference between PMB and control sections, the in-service time when the sections were investigated was quite short (only 5 years) and this normally is not long enough to see pavement damage like rutting and cracking. In Table 1, there was also an investigation on various polymers (SBS, SBR, EVA, and LDPE) which showed no clear trends in terms of rutting resistance but tendency for brittle failure for EVA sections (Stroup-Gardiner and Newcomb, 1995).

Table 1. Investigations on field performance of PMBs in Europe and North America

Year of investigation	Location of sites	Number of PMB sections	Polymer information	In-service time when investigated	Conclusions	References
1990	Belgium	1	SBS, EVA, Tyre rubber	5 years	The general condition of those test sections was still good. PMBs showed the potential to improved asphalt performance with best results for SBS and EVA.	Francken, 1990
1990	USA, Canada and Austria	> 30	Various including SBS, SBR, PE and EVA	< 5 years	No significant difference was observed between PMB and control sections.	Button, 1992
1993	USA	6	Various including SBS, SBR and EVA	Varied up to 6 years	No significant difference as compared with control sections.	Elmore et al., 1993
1993	UK	> 20	SBS, EVA, Crumb rubber	6-9 years	No significant difference as compared with control sections.	Colwill et al., 1993
1995	USA and Canada	20	Various including SBS, SBR, EVA and LDPE	Varied up to 9 years	No clear trends in terms of rutting resistance. EVA sections showed a tendency for brittle failure.	Stroup-Gardiner and Newcomb, 1995
1995	Australia	2	SBS, EVA	5,5 years	Both rutting and fatigue performances were improved by PMBs.	Maccarrone et al., 1995
2002	USA	1	Various including SBS, SBR and LDPE	11 years	Most of test sections with PMB (except for LDPE) showed improvement in cracking performance.	McDaniel and Shah, 2003
2004	Switzerland	16	Various including SBS, EPDM, PE and EVA	19 years	Improved cracking resistance for PMBs, especially SBS modified.	Dumont and Ould-Henia, 2004
2004	USA	8	Various polymers including SBS, SBR, Crumb, rubber and PE	8 years	Significant improvement in the rutting resistance observed for SBS and SBR sections	Dumont and Ould-Henia, 2004
2015	Lithuania	3	Not detected but most likely SBS modified bitumen products	7 years	Of the 27 different pavement structures tested, those with PMB in the asphalt wearing layer, and also for the asphalt wearing and binder layers, showed the smallest ruts.	RRi, 2015



3. Field trials in Sweden

Since the 1990s, several well-planned field trials have been carried out on PMBs. These trials are briefly summarised in Table 2 and analysed in the following sections.

Table 2. Field trials of PMBs in Sweden

Year of construction	Location of sites	Number of PMB sections / reference sections	Objectives	Year of follow-up investigation	References
1990	E6, Kallebäck-Åbro, Gothenburgh	2 / 4	To investigate use of PMBs in stone mastic asphalt (ABS) and to evaluate long-term effects of polymer modification	1999	Jacobson and Hornwall, 1999
1990	E20, Partille, Gothenburgh	3 / 1	Trials with PMBs in open graded asphalt mix (ABD)	2000	Jacobson and Hornwall, 2000
1991	E18/E20, Örebro-Arboga	6 / 2	Experiment with PMBs in stone mastic asphalt (ABS) and dense grade asphalt (ABT)	1999	Jacobson and Hornwall, 1999
1998	Arlanda Airport, Ramp Rudolf		To test and evaluate asphalt wear courses with different PMBs in order to provide a basis for technical specifications for airport pavements		Edwards et al., 1999
2004 - 2006	E6, Geddeknippel – Kalsås, Uddevalla	8 / 2 (southbound), 3 / 2 (northbound)	To study whether it is cost-effective to use PMB on heavy traffic roads under Nordic conditions and to investigate if functional properties of asphalt pavement can be predicted by binder tests	2007 to 2020	Ahmed et al., 2019; Lu et al., 2014, 2016; Said et al., 2021
2012	V50, Skänninge	7 / 1	To quantify the effect of polymer-modified pavement layers in terms of rutting and IRI (International Roughness Index) compared to standard pavements, based on a long-term follow-up of field trials	2013 to 2019	Edkblad and Lundström, 2021
2015	V40, Ulricehamn	3 / 1 + 1*	To investigate whether it is possible to reduce asphalt thickness by using high performance PMBs compared to traditional types	2022	Ekblad and Gustafsson, 2023
2017 / 2018	E20, Hova	2 PMB / 4 unmodified	To compare the technical properties of asphalt pavements with different amounts of recycled asphalt and to study how recycling can be optimized to lower the carbon footprint of asphalt	2019 to 2023	Ahmed et al., 2025; Olsson, 2018

3.1 Field trials in the 1990s

In the early 1990s, different PMBs were tested in an open graded asphalt mix (Jacobson and Hornwall, 2000). Four test sections were built on a heavily trafficked road E20 in Partille not far from Gothenburgh. After 10 years in service, the rutting was rather high, mainly due to wearing from studded tyres. The analysis of extracted binders from the asphalt cores taken from the road showed a lot of hardening already after 4 years in the field. There seemed not to be any significant difference in the hardening of PMBs compared to the reference bitumen (B85). It was noted that asphalt samples were not taken from the same spot (1994 under wheel tracks but 1999 outside wheel tracks), which might have affected the aging results of extracted binders as seen from results of penetration tests. After 10 years, resistance to water damage of asphalts (as measured by ITSR) also decreased to values of 50% or lower. This was speculated to be connected to increased stone loss. The air void contents of asphalt cores were found to be 5-12%. Production control of asphalt from the mixing plant showed that the binder content was lower than planned, which may affect performance comparison between the PMB and reference sections.

To gain knowledge about stone mastic asphalt (SMA) and modified binders, a road trial with six test sections was carried out in 1990 on the highway E6 between Kallebäck and Åbro in Gothenburg (Jacobson and Hornwall, 1999). The purpose was to compare the wear resistance against studded tyres using PMBs and different types of high-quality stone materials in SMA. After 8 years, the wear from the studded tyres was relatively low (9.5 – 12 mm), and field inspection revealed that all the sections were in good condition. Asphalt cores were also taken from the sections after 8 years. The extracted binder was in very good condition, particularly the PMBs which still had 83% elastic recovery. The cores showed extremely low void content (<1%), which might explain the good aging properties. After 9 years of service, it was concluded that the test sections still performed well. However, the test sections were not followed any more due to re-construction of the road.

In 1991, another test road was constructed again on a high traffic road E18/E20 (ADT 11500,19% trucks) outside Örebro (Jacobson and Hornwall, 1999). The test roads consisted of six sections made of six different types of PMBs (four supplied by Nynas) and two reference sections with unmodified penetration bitumen (Table 3). Two different types of asphalt mix were investigated, stone mastic asphalt ABS (or SMA in English) and dense asphalt ABT. The test road was monitored every year during the first four years (to 1995) and finally followed up in 1999 before it was partly removed due to construction of a new motorway at that time. The different bitumen and asphalt materials were investigated by various laboratory tests and field inspections were made on the road along with analyzing asphalt cores taken from the road at different ages.

Table 3. Test sections on E18/E20

Sections	Wearing course	Type of binders
1	ABS16	PMB, 4% polymer
2	ABS16	PMB 20 without fiber, 6% polymer
3	ABS16	PMB 20 with fiber, 6% polymer
4	ABT16	PMB, 6% linear polymer
5	ABT16	PMB, 6% polymer with penetration 180
6	ABS16	PMB, Styrelf
7	ABS16	B85 (reference)
8	ABT16	B85 (reference)

ABS = Stone mastic asphalt; ABT = Dense graded asphalt

After 10 years in service there was only limited wearing due to the studded tyres. The ABS sections were best with no significant difference between PMB and regular bitumen. There was more wearing on the ABT sections, but it was lower with PMB sections. There was no permanent deformation. A laboratory test, static creep, was used to estimate the deformation sensitivity at the start of the trial. All sections (except for the ABT reference) were considered to be sensitive to permanent deformation. However, the field experience showed totally contradictory results. One explanation for the low deformation and wear sensitivity might be the fact that the road was a so called 13 m road (the width), thus the traffic did not always run in the same tracks.

The inspection after 10 years showed that most sections were in excellent condition. There was, however, some stone loss, particularly during the first years. Also, some longitudinal cracking started to appear particularly on the ABT reference, and this was accompanied by some stone loss. Extracted binder from asphalt field cores showed limited aging after 10 years. The penetration was almost constant for the PMBs while the unmodified bitumen hardened as usual. There was a drop in the R&B temperature of the PMBs, however a lot of elasticity remained (about 90% elastic recovery).

Although further long-term follow-up had not been carried out because the test road was partly removed (as mentioned above), this field trial and 10-year follow-up already showed an excellent durability (aging-resistance measured by elastic recovery as well as penetration) for the PMB binders. In addition, ABS showed better wearing resistance than ABT, and PMB binders gave an advantage over unmodified bitumen in this respect.

In the 1990s, a field trial was also carried out for airfield paving (Edwards, et al., 1999). It is known that airfield paving has very high requirements for bituminous materials, especially with respect to resistance to permanent deformation and shearing, resistance to low temperature cracking, resistance to aging and resistance to de-icing agents. To develop a technical specification for airport pavements, the trial was carried out by the Swedish Aviation Administration in 1998 on asphalts with different PMBs on Arlanda's Ramp Rudolf. Based on this extensive investigation, a performance grade (PG) system developed in the U.S. during the Strategic Highway Research Program (SHRP) was adopted for binders in airfield applications. Since then, PMB has been commonly used in airport runways, and in 2025, a runway of Arlanda airport was again re-paved with PMB and this time by using a biogenic-containing PMB of low carbon footprint (Nynas, 2025).

3.2 Test road E6 Uddevalla

As part of the E6 motorway north of Uddevalla, a test road Geddeknippel–Kalsås was built in 2003–2006 (Malmqvist and Aksell, 2006). The road was opened to traffic in 2004, with the binder course being trafficked until the wearing course was laid in September 2006. Ten test sections were constructed on a southbound section with different types of PMBs that replaced standard bitumen in the base, binder and wearing courses (see Table 4). Five test sections were constructed on the wearing course with different PMB asphalts on the northbound section. The types of polymers used were SBS and EVA. The test sections were planned by the Swedish Road Administration (Trafikverket) in collaboration with several industrial partners.

Table 4. Description of test sections on E6 Geddeknippel–Kalsås with various combinations of binders*

Southbound sections	Ref 1	1a	1b	2a	2b	3a	3b	4a	4b	Ref 2
Length (m)	400	275	275	124	226	128	292	398	102	260
Wearing course 40 mm SMA 16	70/100	70/100	50/100-75 SBS			70/100				70/100
Binder course 50 mm ABb 22	50/70	50/70	50/70-53 EVA				50/70-53 SBS			50/70
Upper base course 50 mm AG 22	100/150	100/150-75 SBS		100/150						100/150
Lower base course 50 mm AG 22	100/150	100/150-75 SBS		100/150	160/220	160/220	100/150	160/220	100/150	100/150

Northbound sections	1	Ref 1	2	Ref 2	3
Wearing course 40 mm SMA 16	50/100-75 4% SBS	70/100	50/70-53 EVA	70/100	50/100-75 6% SBS

* Currently, 50/70-53 = 45/80-55; 50/100-75 = 40/100-75; 100/150-75 = 90/150-75

The main objectives of constructing the test road were to gain knowledge about various aspects of using PMBs on heavy traffic roads under Nordic conditions, such as cost-effectiveness and relevance of laboratory tests. Follow-up projects were carried out to evaluate the test sections, including field measurements, drilling and analysis of asphalt cores, as well as long-term performance prediction (Ahmed et al., 2019; Lu et al., 2014, 2016; Said et al., 2021). The testing and performance follow-up program is briefly shown in Table 5. Asphalt cores were taken from the southbound sections in September 2010 and from the northbound sections in August 2022.

Table 5. Testing program and pavement performance follow-up of the test road E6

Binders			Asphalt field cores	Test Sections
Virgin	RTFOT.PAV	Recovered	<p>Mechanical tests</p> <ul style="list-style-type: none"> • Dynamic shear test • Creep test • Stiffness by indirect tensile test (IDT) • IDT fatigue test <p>Mix composition analysis</p> <ul style="list-style-type: none"> • Binder extraction / recovery • Air voids • Binder contents 	<p>Performance follow up</p> <ul style="list-style-type: none"> • Falling weight deflection (FWD) • Rut and transverse profile (Primal) • Rut depth measurement • Regular inspection • Field sampling
<p>Binder evaluation</p> <ul style="list-style-type: none"> • Conventional tests (penetration, softening point, etc.) • Morphology • Dynamic shear rheometer (DSR) <ul style="list-style-type: none"> • Frequency-temperature sweep • Low shear viscosity (LSV) • Multiple stress creep and recovery test (MSCRT) • Chemical analysis <ul style="list-style-type: none"> • Gel permeation chromatography (GPC) • Fourier transform infrared spectroscopy (FTIR) 				

By DSR analysis, the SBS modified binders were found more elastic than reference bitumen and EVA modified bitumen. In the DSR master curves, the SBS modified binders also showed significantly higher modulus at low frequencies (or high temperatures) than the reference bitumen, as exemplified in Figure 1. Using the rutting parameters G^*/\sin and low shear viscosity determined at different temperatures (40 and 60°C), the rutting resistance of the binders were ranked as: 50/100-75 SBS > 70/100 in the wearing course, and 50/70-53 EVA > 50/70-53 SBS > 50/70 in the binder course.

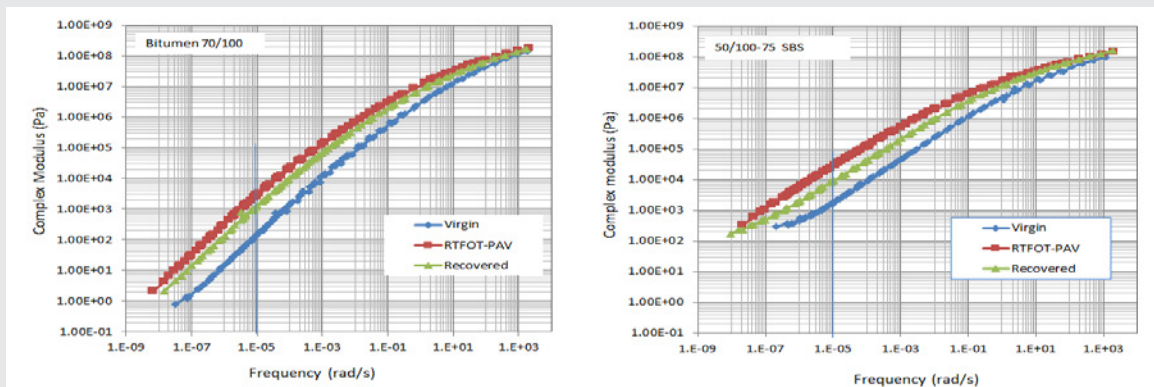


Figure 1. Master curves of complex modulus at ref temperature of 10°C (Lu et al., 2021)

The MSCRT was performed at 60°C on all the samples, including virgin (unaged), laboratory aged, and those extracted from the test road after 4 years in-service. Typical examples of the MSCR curves are shown in Figure 2, and the obtained strain recovery (R) and non-recoverable compliance (Jnr) are shown in Figure 3. It is evident that PMBs show much higher strain recovery and lower non-recoverable compliance as compared to the unmodified bitumen, suggesting strong structural networks and high rutting resistance for the modified binders.

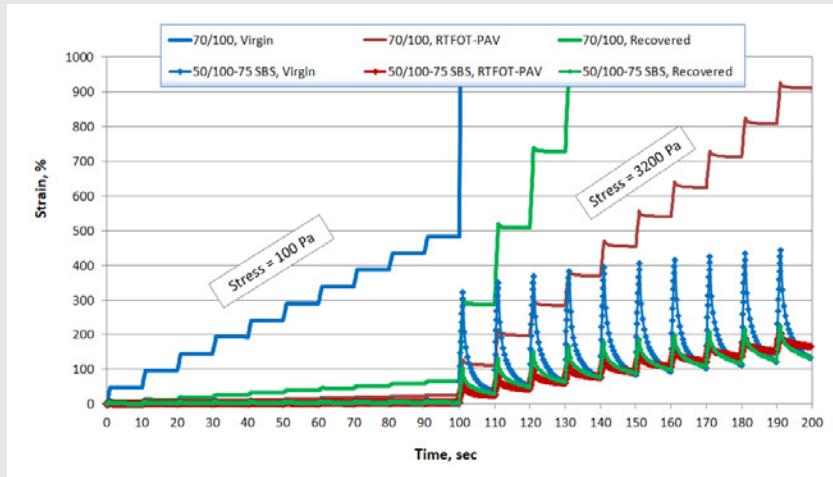


Figure 2. MSCR tests at 60°C for unmodified bitumen and PMBs (Lu et al., 2021)

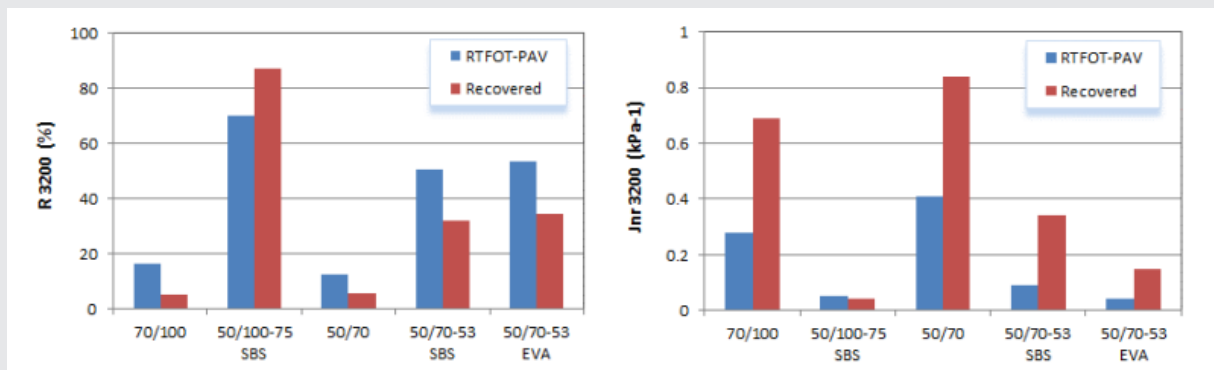


Figure 3. MSCRT results at 60°C for unmodified bitumen and PMBs (Lu et al., 2021)

MSCR tests also show that the binders are less prone to deformation after aging due to the increased binder stiffness. For the unmodified bitumen, as well as for the EVA modified, aging increases strain recovery and decreases the non-recoverable compliance. Such aging effects are positive with respect to rutting performance. In the case of the SBS modified binders, inconsistent changes may be observed in the MSCR parameters, depending on a combined effect of bitumen oxidation and polymer changes. Nevertheless, the SBS modified binders, especially the one used in the wearing course (50/100-75 SBS), show significant improvement by the MSCR parameters. The MSCRT was also performed at 40°C. Similar trends were observed with advantages for the modified binders, but differences between the binders became smaller compared to the results at 60°C.

By the rheological measurements, the aging sensitivity of the different binders was evaluated. Of the binders used in the test road, the SBS modified binders were found to be the most resistant to aging. The improved resistance to in-service aging of the SBS modified binders was verified by a small change in asphalt stiffness in the field.

On asphalt properties, stiffness measurements were conducted on asphalt mixes at different temperatures using indirect tensile test (IDT). Based on the results at 10°C, aging indices of the asphalt cores, defined as relative increase in stiffness modulus per year in percentage, were calculated (Figure 4). In both wearing and binder courses, the asphalt mixes made of the SBS modified binders were less aged than those with other binders, confirming the observation on the binders. In the case of the base course, the mix with the SBS modified binder displayed a slightly higher aging index than the unmodified one, for which an exact reason was not given.

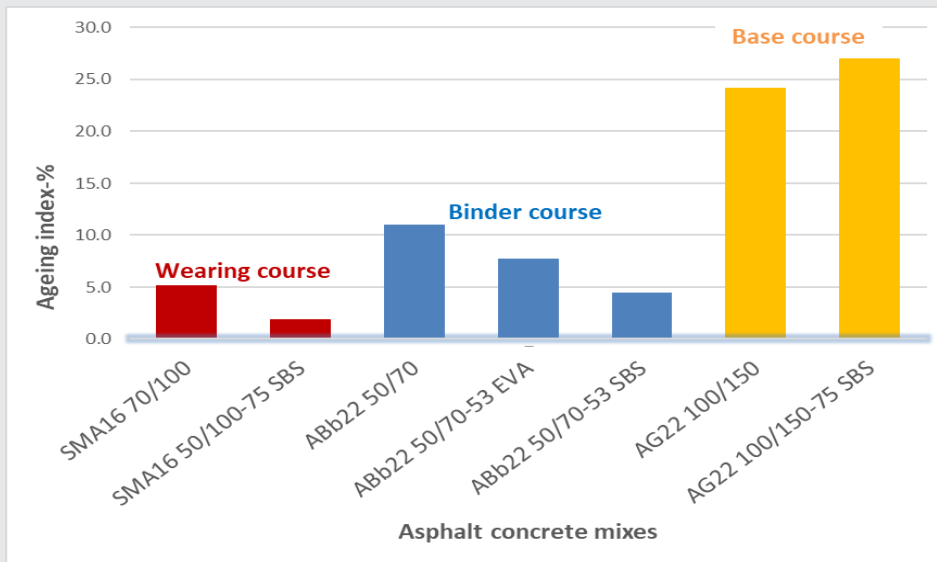


Figure 4. Aging sensitivity of asphalt mixes (Ahmed et al., 2019)

The permanent deformation of asphalt mixes was assessed by dynamic shear modulus tests at different frequencies and different temperatures. From the master curves in Figure 5, the surface course mixes (SMA 16) with the modified and unmodified binders behave quite similarly over a broader frequency and/or temperature range. However, in terms of phase angle, the SBS-modified surface mix displays a lower value than the unmodified mix, indicating a better elastic property, which should be beneficial for the resistance to permanent deformation, as well as fatigue cracking.

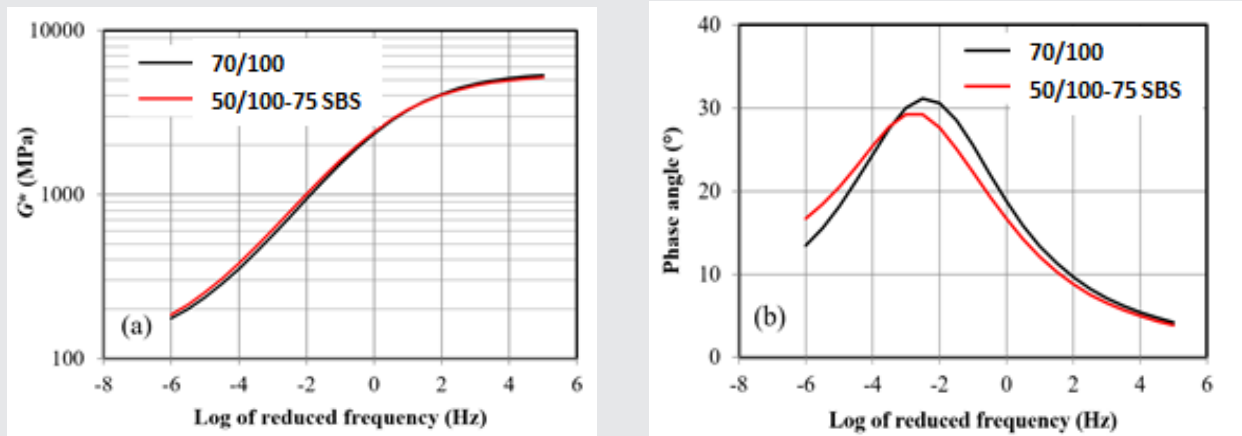


Figure 5. Master curves of dynamic shear modulus and phase angle of SMA 16 at a reference temperature of 10°C (Ahmed et al., 2019)

With respect to fatigue cracking, the reference sections Ref 1 and Ref 2 with conventional base mixes and the sections 1a and 1b with SBS-modified bitumen base mixes were investigated by indirect tensile (IDT) fatigue tests at 10°C. Based on the developed fatigue lines and the strain calculated from the measurements made by the falling weight deflectometer (FWD) in September 2012, the estimated allowable number of ESALs to fatigue cracking of the base courses were determined. It was concluded that the SBS-modified base mix was significantly better in fatigue cracking resistance than the reference one (Figure 6), and the pavement structures with the modified bitumen in the base mixes demonstrated at least 34 years' longer fatigue life than the conventional structures (Ahmed et al., 2019).

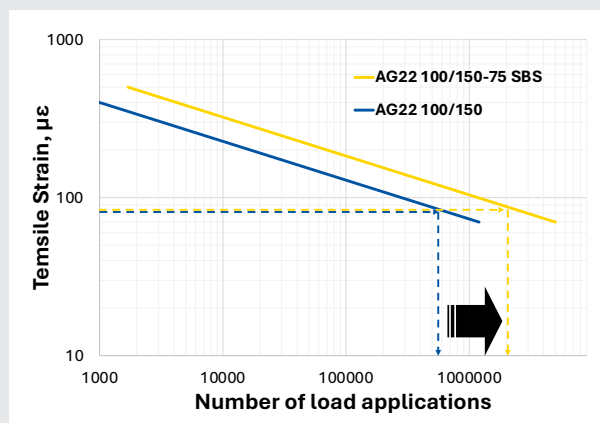


Figure 6. Fatigue lines determined from asphalt field cores (Ahmed et al., 2019)

On field performance, the southbound test sections had been monitored from 2006 until 2017 by regular field inspections and rut depth measurements using a high-speed Road Surface Tester (RST). In general, all the sections remain in good condition; no distresses, such as stripping and cracking, were observed. A rut depth development of approximately 4 mm was found after a 10-year in-service and rather small differences (< 1 mm) were observed between the different sections. A significant contribution to the small differences in rutting was the varied age-hardening (stiffness change) of the asphalt materials, and those with the SBS modified binders showed much less aging over time.

The rut developments on the asphalt layers of the test road during the past years were also evaluated using PEDRO (PERmanent Deformation of asphalt concrete layers for ROads) and permanent deformation over an analysis period of 20 years was further predicted. In general, all the sections were predicted to show small rutting (< 5 mm), suggesting that over-designed strong structures were made for the test road. But certain differences do exist between the different sections, with lower rut for the PMB sections (Figure 7). The section 1a with the SBS base course mix shows less measured and predicted rutting compared to the reference section with conventional binder in all asphalt layers and the section 2a with PMB in all bituminous layers shows least rutting.

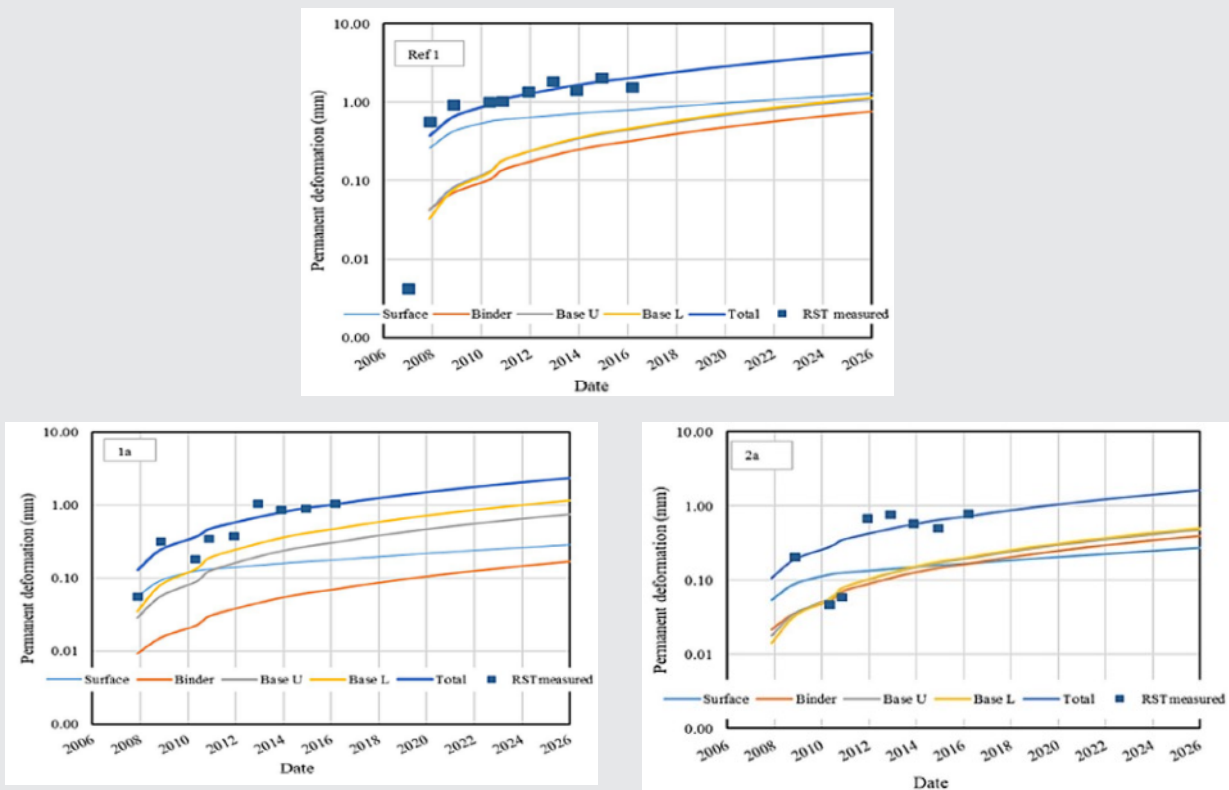


Figure 7. Measurement and prediction of the permanent deformation of the section with conventional bitumen (Ref 1) compared to the sections 1a with PMB in base course and 2a with PMB in surface and base courses (Ahmed et al., 2019)

A more recent inspection and asphalt coring were made on the northbound sections just before re-surfacing in August 2022 (Figure 8). The observed surface cracking damage was ranked as: Section EVA modified > Section Reference 70/100 \geq Section 4% SBS modified > Section 6% SBS modified; the section with the 6% SBS modified binder was the best (almost no cracks) whereas the section with the EVA modified binder was worst. The asphalt cores were then investigated with respect to aging evolution and fatigue performance (Zhang et al., 2025). It was found that differences in the aging susceptibility of the binders lead to significant difference in the pavement fatigue life (Figure 9). The predicted fatigue life of road section built with SBS modified bitumen was 1.35 to 1.5 times longer than the fatigue life of the road section built with unmodified bitumen, supporting field performance observations.



Figure 8. Surface cracks (load and fatigue induced) on the northbound sections and field cores in 2022 (after 16 years in service)

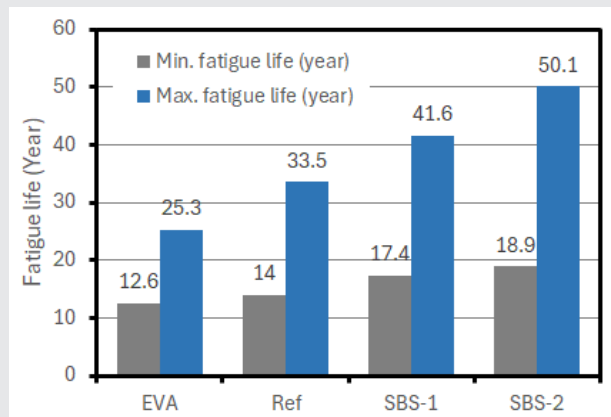
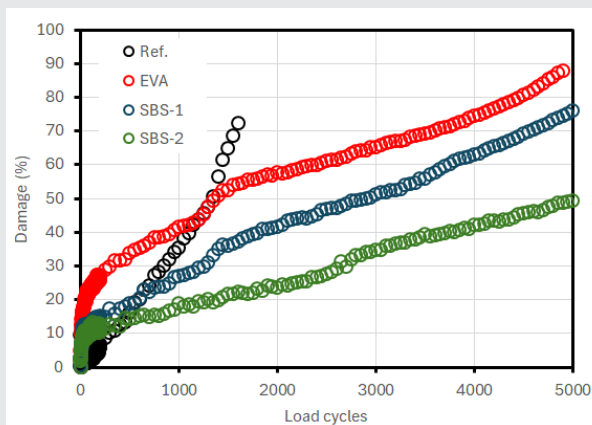


Figure 9. Comparison of fatigue performance of the northbound sections, laboratory testing of field cores (left) and fatigue life prediction (right) (Zhang et al., 2025)

3.3 Test road RV 40 Ulricehamn

The test road consisting of five sections (2 km long in total) was built on the national road 40 (RV 40) in Ulricehamn and opened to traffic in the autumn 2015. The main objective was to investigate whether it is possible to reduce asphalt thickness by using higher performance PMBs compared to traditional types. The selected pavement structures and materials are shown in Table 6 (Gudmarsson, 2015). In addition to conventional penetration bitumen, two PMBs were used in the test sections, including 45/80-65 and 25/55-80, which contain 4% and 7.5% SBS, respectively. The reference section consisted of 190 mm bonded layers while the four test sections had 140 mm bonded layers. The reference section and test section 1 were built according to the standards with conventional materials but differed in the thickness of the bonded layers. Test section 2 employed entirely a stiffer bitumen (50/70) in three asphalt layers, while test sections 3 and 4 used two different SBS modified binders.

Table 6. Pavement structures and materials of test road Rv40

K1 Eastbound	Reference 500 m	P1 375 m	P2 375 m	P3 375 m	P4 375 m
Wearing course ABS 16, 40 mm	70/100 (6.4%)	275	50/70 (6.5%)	45/80-65 (6.5%)	25/55-80 (6.6%)
Binder layer ABb 22, 50 mm		50/70 (5.0%)		45/80-65 (5.1%)	25/55-80 (5.3%)
Base layer AG 22, 50 mm	70/100 (4.6%)	160/220 (4.4%)	50/70 (4.7%)	45/80-65 (4.9%)	25/55-80 (5.2%)
Base layer AG 22, 50 mm	160/220 (4.4%)	Unbound			

In laboratory tests, various beneficial effects of using PMBs have been shown, including improved fatigue and deformation properties, and enhanced resistance to low temperature cracking (Gudmarsson, 2016). As exemplified in Figure 10, the base course asphalt mixes (AG 22) with the polymer modified binders perform much better than those with unmodified bitumen in terms of fatigue resistance. By using PMBs instead of 160/220 bitumen in the base course, the number of load cycles to failure increases by at least 3.5 times for the PMB pavements. As for the low-temperature properties, the thermal stress restrained specimen test (TSRST) results show that the degree of modification affects the pavement's capability against low temperature cracking. The positive effect of PMBs on the low temperature cracking can become even more evident when aging is considered (Isacsson and Zeng, 1998).

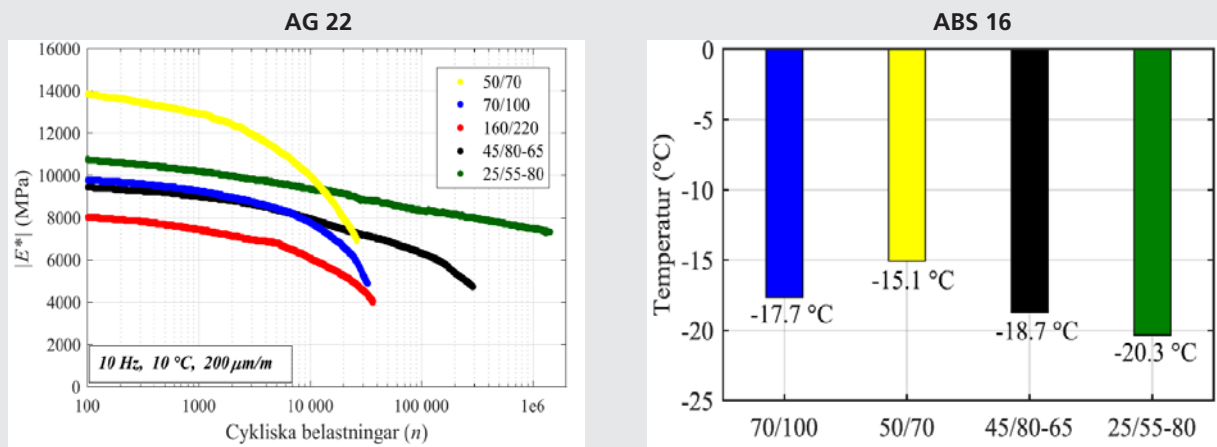


Figure 10. Results of 4-point bending fatigue test (left) and thermal stress restrained specimen test (right)

Surface measurements on the test road surface measurements have been carried out twice a year from 2016 to 2022, spring and autumn; those included longitudinal smoothness (IRI, International Roughness Index) and rut depth (Ekblad and Gustafsson, 2023). The traffic volume on the road was 5,700 vehicles/day (ADT in 2019), of which 17% were heavy vehicles. After 6 years, all test sections were in good condition with relatively low rut depth development and no cracking. The rutting development was the lowest in the PMB sections (0.23 – 0.32 mm/year) and highest in the standard pavements (0.41 – 0.43 mm/year). The unexpected relatively small effect from the highly modified binder 25/55-80 on section P4 can be related to reduced stiffness of the asphalt. This section had high air voids possibly due to issues with workability of the highly modified asphalt.

Despite the intention to under-dimension the road, it was concluded that the test road was well-built with a high technical performance level, indicating that roads are in general built to a high standard. There are no signs that a thickness reduction of 50 mm in the bonded layers by using PMBs would negatively affect road performance. However, it was also emphasised that a 6-year follow-up is fairly short time in a road context. There are additional degradation mechanisms such as cracking and lack of durability, which have not been studied yet as they normally occur in an even longer time perspective.

3.4 Test road RV 50 Skänninge

The test road on RV50 was built in 2013 between Mjölby and Motala close to Skänninge as part of a Design-Build-Maintain contract awarded by the Swedish Transport Administration (Ekblad and Lundström, 2014). It was designed as a so-called 2k factorial experiment, considering three factors (i.e. three construction layers) varied at two levels in terms of binder type (Reference bitumen binder or high-performance PMBs). The pavement structure comprises three asphalt layers (35 mm surface layer, 50 mm binder layer, and 65 mm base layer) on top of unbound base and subbase layers of crushed rock (500 mm). In total, 8 test sections were constructed (Figure 11). The bituminous binders used in the different asphalt layers are shown in Table 7. It should be noted that for the surface layer, a modified binder was also used as Reference. The exact type of the modified binder was not disclosed but the degree of modification is low, and the rheological characteristics of the modified binder are rather close to a penetration grade bitumen.

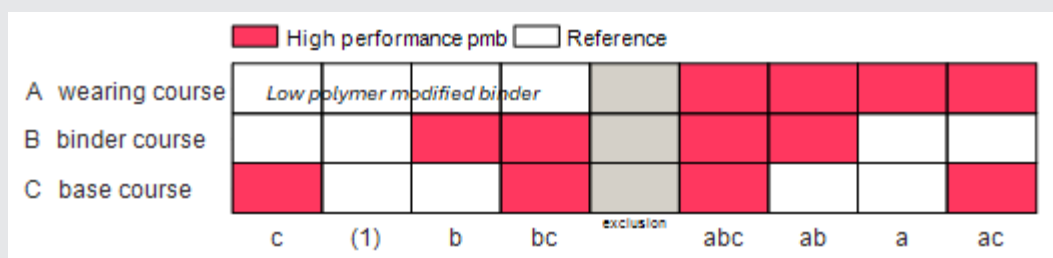


Figure 11. Experimental planning of the test road on RV 50

Table 7. Bituminous binders used in the different asphalt layers

Layer	Mix type	Binder	
		Ref	PMB
Surface	Dense asphalt (Viacogrip 16)	Pmb 45/80-50	Nypol 76-28
Binder	ABb 16	50/70	Nynas Endura Z3
Base	AG 22	70/100	Nynas Endura F1

During and after paving, the different test sections were subject to quality control to ensure that the asphalt composition was within specifications; non deviations outside normal production specifications were observed. Laboratory testing of resistance to permanent deformation was performed on both cored samples from the pavement and samples manufactured in the laboratory from asphalt mix sampled during production. Tests included wheel-tracking test and cyclic compression test. In general, the mixes with PMB showed higher resistance to permanent deformation than those with reference binders.

The performance of the test road has been monitored particularly in terms of rutting based on measurements of surface evenness using an inertial-based profiler driving at normal traffic speeds (Ekblad and Lundström, 2021). In addition, macrotexture was measured using mean profile depth (MPD) as an indicator of possible surface deterioration. For the first 8 years, the surface was measured at least twice a year (one in the spring and one in the fall), then measured at least once a year. Figure 12 shows rut depth measured in the first year (2013) and after six years in 2019. To indicate variability, values are shown as mean values over 1 m of road and as mean values for each individual test section. It was also reported that, on average, 70 % of the rutting occurred during summers, which are attributed to heavy traffic.

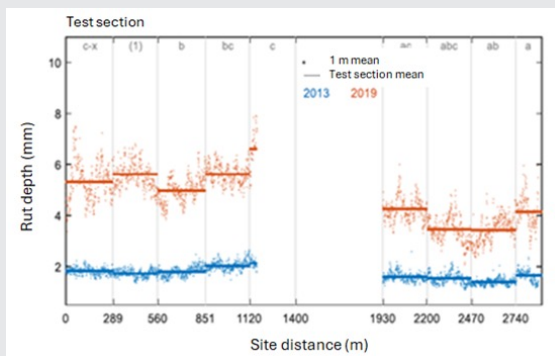


Figure 12. Initial and final rut depth, 1 m-mean values as dots and test section mean values as lines (Ekblad and Lundström, 2021).

Overall, rutting was relatively limited compared to maintenance standards. A comparison was then made by looking at annual rut depth increase (Figure 13). Evidently, rutting is lower on the sections with PMB, especially on the sections using PMB in the surface layer. At the same time, it was stated that the sections with PMB in the surface layer are located in a curve, and a statistic analysis indicated that curved sections tended to give less rutting compared to straight sections with a narrower driving pattern. Despite this confounding effect, PMB sections did show less rutting as compared to the reference sections, but the improvement in the field after six years was not at a level expected from laboratory tests on binders and asphalts. The positive effects of using PMB on rutting resistance is further confirmed by 11 years follow up (NCC, 2025). In addition, there were no cracks, nor any obvious surface deterioration, such as fretting or potholes, caused by durability issues, from either visual observations or macrotexture measurements.



Figure 13. Annual rut depth increase (mm/year) for each section in increasing order; red fill indicates asphalt layers with PMB (Ekblad and Lundström, 2021)

3.5 Test road E20 Hova

In 2017 and 2018, six test sections were built on the E20 Hova with different levels of recycled asphalts (RA) in the binder course and base course (Olsson, 2018). The test sections were divided into two test series (Table 8), one series of three sections was based on penetration bitumen and rejuvenators, and another series of three sections used recycled asphalt in PMB asphalt mixes. This project was primarily intended to study how recycling can be optimised to lower the carbon footprint of asphalt. The performance follow-up of the test sections and corresponding predictions made recently (Ahmed et al., 2025) showed that choosing PMB as the binder significantly increases the lifetime of asphalt, both in terms of rutting resistance (Figure 14) and fatigue (Table 9).

Table 8. Description of test sections on the E20 Hova

Sections	Base course	Binder course	Wearing course
1, Reference	AG22 70/100, 30% RA	ABb22 50/70, 20% RA	ABS16 70/100
2	AG22 70/100, 50% RA, Rejuvenator	ABb22 50/70, 30% RA, Rejuvenator	
3	AG22 70/100, 50% RA, Soft bitumen	ABb22 50/70, 30% RA, Soft bitumen	
4, Reference	AG22 70/100, 30% RA	ABb22 50/70, 20% RA	
5	AG22 40/100-75 PMB, 30% RA	ABb22 40/100-75 PMB, 20% RA	
6	AG22 40/100-75 PMB, 0% RA	ABb22 40/100-75 PMB, 0% RA	

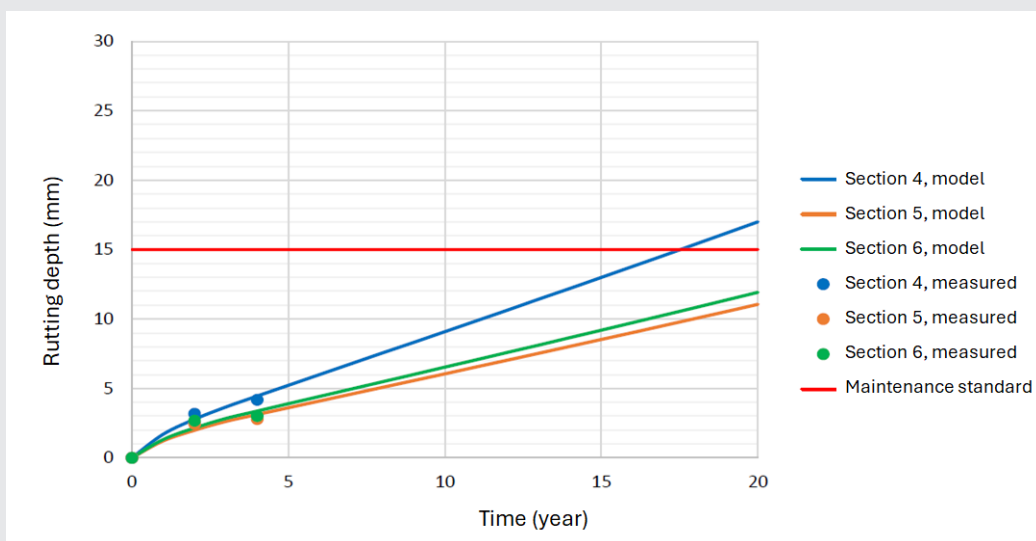


Figure 14. Measurement of rutting depth and prediction by PEDRO for the PMB sections (Sections 5 and 6) and Reference Section 4 with unmodified bitumen (Ahmed et al., 2025)

Table 9. Fatigue life of the base course asphalt mixes

Sections	Base course	Lifetime (years)
1, Reference	AG22 70/100, 30% RA	12
2	AG22 70/100, 50% RA, Rejuvenator	12
3	AG22 70/100, 50% RA, Soft bitumen	10
4, Reference	AG22 70/100, 30% RA	28
5	AG22 40/100-75 PMB, 30% RA	>40
6	AG22 40/100-75 PMB, 0% RA	>40



4. Bridge applications

Apart from the standard requirements for road paving, such as resistance to permanent deformation and resistance to cracking, asphalt pavement on bridge decks must meet certain additional demands (EAPA, 2013). First, asphalt layers need to protect and seal the underlying supporting structure to ensure a long service life for bridges. They must protect bridge structure from surface water or moisture, especially salt water from de-icing agents or when bridges are over sea water, to avoid deterioration or corrosion. In case of a steel bridge of long suspension, large deflections due to dynamic traffic loadings are expected, suggesting that deck pavements also need to tolerate large deformation and at the same time exceptionally resist fatigue. To meet all these requirements, it is rather difficult to use asphalts with conventional bitumen, especially in regions having a wide span of climatic temperatures. Thus, PMBs are often the best choice for asphalt paving on bridge decks. Two examples are the High Coast Bridge (Högakustenbron) and the Öresund bridge (Lu et al., 2016; 2025).

The High Coast Bridge is a suspension bridge (about 1800 meters long) over the Ångermanälven River and on the highway E4 in northern Sweden. The bridge was constructed between 1993 and 1997 and was officially opened on 1 December 1997. Very extensive laboratory and field investigations were carried out on different waterproofing and pavement systems intended for the bridge (Edwards & Westergren, 2001). The system finally selected is illustrated in Table 10. It consisted of two layers of epoxy, an SBS-modified bitumen sheet layer, a binder course of polymer modified mastic asphalt (PGJA 8), and a wearing course of polymer modified stone mastic asphalt (ABS 11). In the asphalt surface and binder layers, two different SBS modified binders were used. The High Coast region is exposed to a wide temperature span and large temperature fluctuations. The average temperature in winter is around -20°C with the coldest weather down to -40°C, while summer temperature can be as high as 30°C. Moreover, as a part of the highway E4 in northern Sweden, this bridge withstands relatively high traffic density (ADT of about 3000 vehicles/day) and a high proportion of studded tyres. Despite the tough climatic and traffic conditions, the PMB asphalt pavement on the bridge had performed excellently, after almost 15 years in service, no cracks (fatigue or low temperature cracking) and only very limited rutting were observed by a field inspection. The good performance was also confirmed by performance data recorded in the Swedish Pavement Management System (PMS) database. As a preventive measure for potential stone loss which would subsequently damage the paint of the steel bridge, the Swedish Transport Administration decided in 2012 to replace the top asphalt layer (ABS11 with PMB 20, 75/150-80) with a similar asphalt material although the top asphalt layer was still in a very good condition.

The Öresund Bridge is a double-track railway and motorway bridge on highway E20 across the Öresund strait between southernmost Sweden and Denmark. The bridge is about 8 km long and was inaugurated on the 1st of July 2000. As shown in Table 8, the waterproofing and paving system used on this concrete bridge deck consisted of two layers of epoxy primer, 5 mm polymer modified bituminous sheet, 30 mm polymer modified mastic asphalt (PGJA 11), and 45 mm wearing course made with polymer modified stone mastic asphalt (ABS 16). The PMBs used in the asphalt wearing course and binder course were the same as on the High Coast Bridge. The bridge pavement had been heavily trafficked (ADT > 15000 vehicles/day) for 20 years when resurfacing was needed.

Table 10. Paving and waterproofing systems of bridge decks

High coast bridge	Öresund bridge
ABS 11 with PMB 20, 35 mm	ABS 16 with PMB 20, 45 mm
PGJA 8 with PMB 32, 21 mm	PGJA 11 with PMB 32, 30 mm
Polymer modified bituminous sheet, 3.5 mm	Polymer modified bituminous sheet, 5 mm
One layer of epoxy + One layer of epoxy primer	Two layers of epoxy primer
Steel	Concrete

During the re-surfacing operation, reclaimed asphalt pavement (RAP) samples (after 15 and 20 years in service) were collected from the bridge surface layers to study the durability of the PMBs. Extensive chemical and rheological tests were carried out on the recovered binder, as well as on the original PMB sample. For comparison, laboratory aging tests were also performed. Results of conventional tests (Table 11) indicated that, after a long service time on the bridges, the polymer modified bitumen had little change in softening point. The modified binder also retained very good low temperature properties as indicated by fracture toughness test and Fraass breaking point. In addition, a very small change was observed in the elastic recovery, both the original and recovered binders were highly elastic. This is attributed to strong polymer networks in the binders even after a long time in-service.

Table 11. Results of conventional tests

Analysis	Method	Original	15 years field aged (High Coast Bridge)	20 years field aged (Öresund Bridge)
Penetration at 25°C, 1/10 mm	EN 1426	109	54	54
Softening point R&B, °C	EN 1427	83.5	81.0	70.0
Fraass breaking, °C	EN 12593	-25	-20	-20
Elastic recovery at 10°C, %	EN 13398	98	80	73

DSR analysis showed that the PMB displayed much higher elasticity (lower phase angles) at temperatures of about 20 to 90°C and higher flexibility (higher phase angle) at low temperatures (< -10°C) compared to the unmodified bitumen. These improved properties were well retained after 15 and 20 years in the field (Figure 15). The modified binder with enhanced elasticity is beneficial to rutting resistance, also to fatigue resistance, especially for a relatively thin asphalt layer on a bridge.

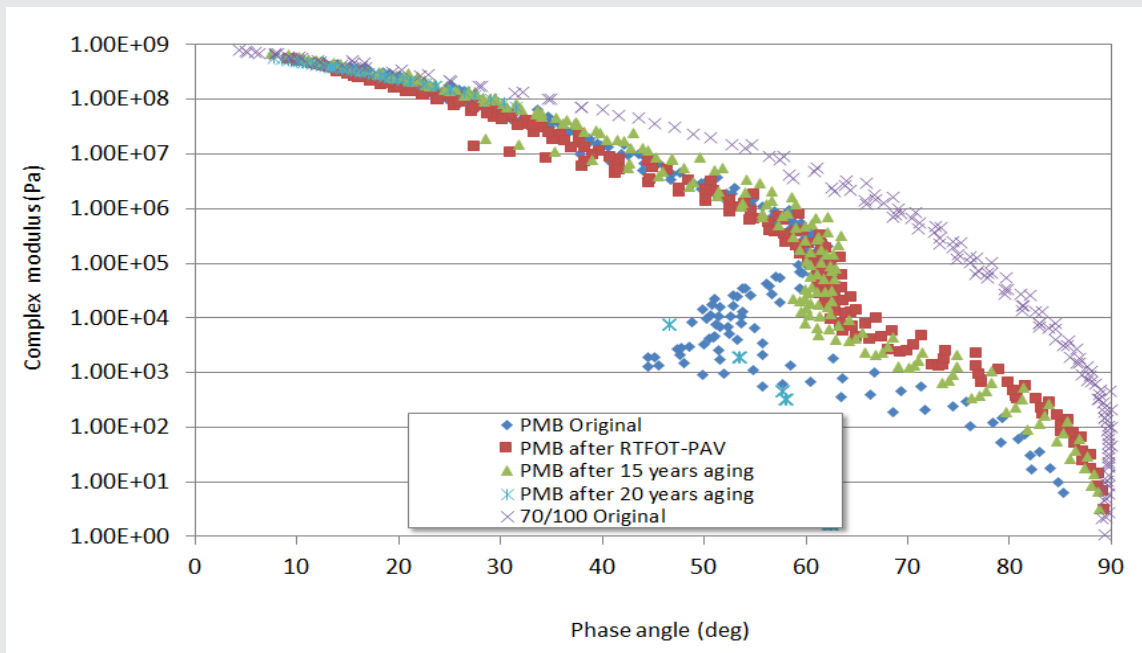


Figure 15. Complex modulus versus phase angle for PMB (unaged and aged) as well as for a penetration bitumen (Lu et al., 2025)

The rutting properties of the polymer modified binder were quantitatively evaluated by MSCR tests at 60°C (Figure 16). It is evident that, after 15- and 20-year in-service on the bridges, the modified binder still retains higher strain recovery and lower non-recoverable compliance. According to AASHTO MP19 (2010), for heavy traffic (> 3 million ESAL's) and very heavy traffic (> 10 million ESAL's), the maximum values of Jnr 3200 are specified to be 2.0 kPa-1 and 1.0 kPa-1, respectively. This would suggest that the polymer modified binder performs according to the heaviest class with respect to deformation resistance.

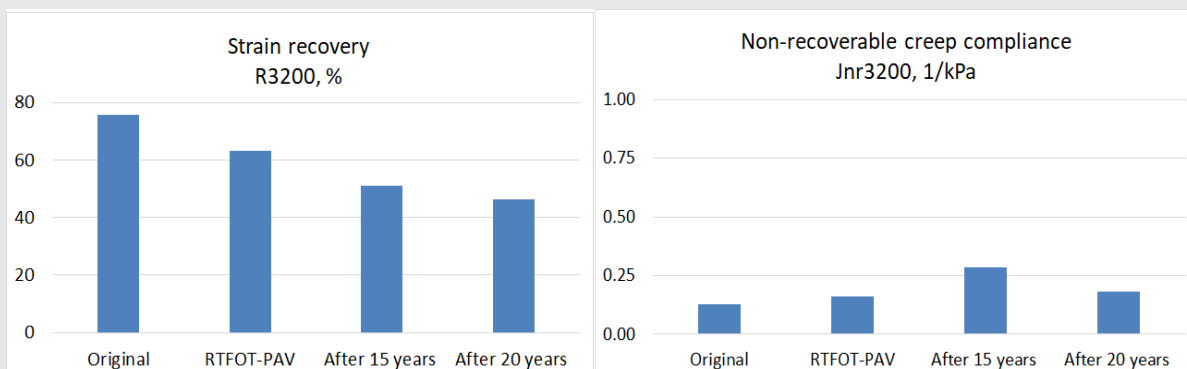


Figure 16. Strain recovery and non-recoverable compliance at 60°C (Lu et al., 2025)

As for low temperature properties, PMB was investigated using BBR (Figure 17). At a temperature as low as -24°C, even after 15 and 20 years in the field, the modified binder far exceeds the low temperature requirement as specified in the American SuperPave binder specification (maximum stiffness at 300 MPa and minimum m-value at 0.300).

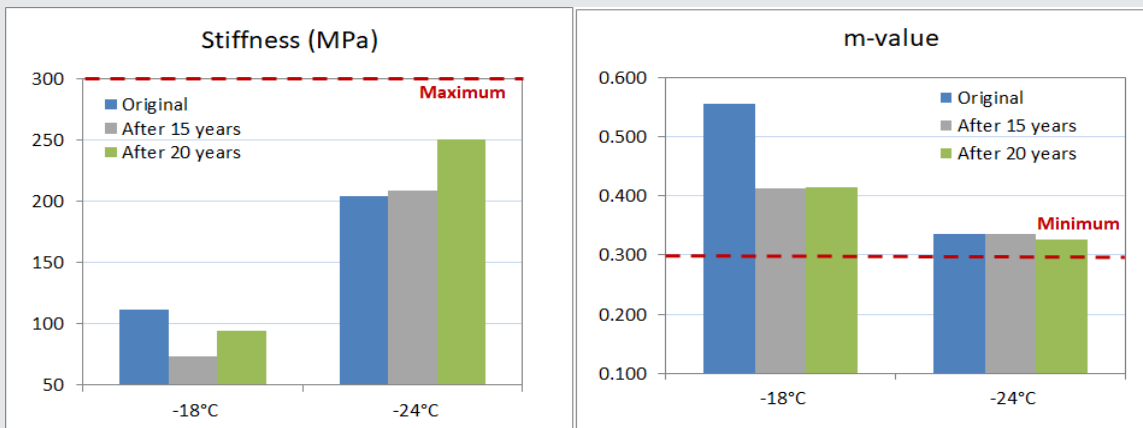


Figure 17. Stiffness and m-value measured at by BBR (Lu et al., 2025)

It is well-known that oxidation causes hardening and embrittlement of bitumen, leading to the deterioration of asphalt pavement. By using polymer modification, the oxidative age-hardening of the bituminous binders can be slowed down. Gel permeation chromatography (GPC) analysis showed that many years in-service increased the molecular weight of the bitumen phase, while there was an opposite change for the SBS polymer (Figure 18). The decrease in polymer sizes is believed to compensate for the oxidative age-hardening of the bitumen components. The well-retained desirable properties for the modified binder are mainly attributed to a strong presence of the polymer and/or fragments of the polymer, as illustrated by FTIR in Figure 19, for the polybutadiene blocks at a wavelength of about 966 cm⁻¹ and for the polystyrene blocks at about 699 cm⁻¹. The good properties retained can bring additional value when the recycling and re-use of the PMB-asphalt is considered.

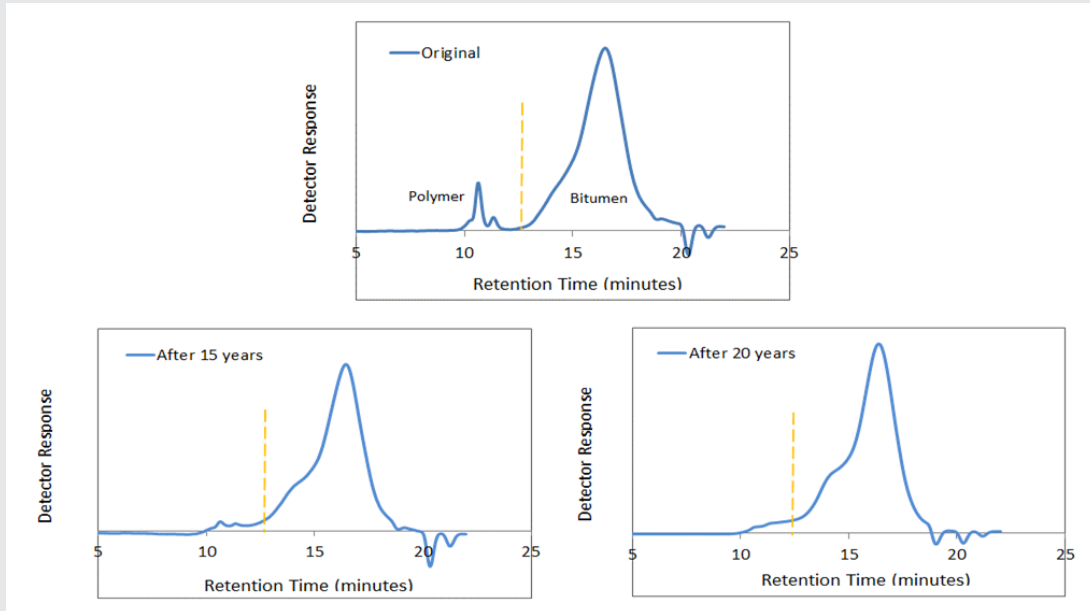


Figure 18. GPC analysis of unaged and long-term field aged PMB

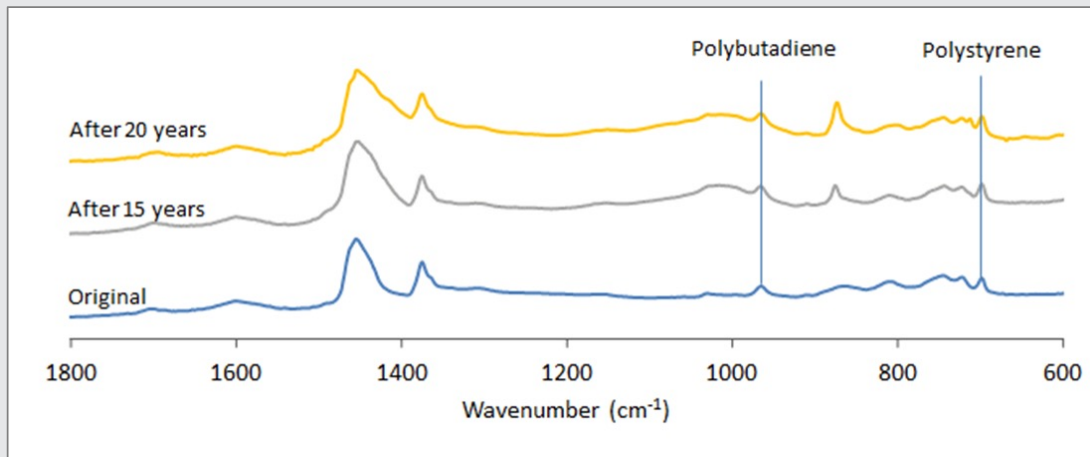


Figure 19. FTIR spectra of unaged and long-term field aged PMB

5. Experience in Norway

In Norway, the use of PMB in asphalt pavements has increased from less than 1 % in 2005, to 10 % in 2010, and to nearly 15 % in 2015 (Jørgensen et al., 2016). This is attributed to various beneficial field evidence shown by PMB (Aurstad et al., 2007; Saba et al., 2012; Jørgensen et al., 2016).

Already in the earlier 1990s, field studies had been conducted with respect to the long-term pavement performance of Norwegian asphalt runways (Aurstad et al., 2007). It was concluded that PMB showed several positive effects (e.g. higher fatigue resistance and higher resistance to aging compared to unmodified bitumen) and was expected to be more utilized in Norwegian pavements, both on roads and airfields.

To study the effect of PMB in asphalt surfacing layers on rutting performance, seven test sections were constructed on the highway E18 in southern Norway in September 2001 (Saba et al. 2012). The test sections were built adjacent to each other on the same subgrade material and were subjected to the same traffic loading and climatic conditions. The ADT at the time of opening the test sections in 2001 was slightly above 16 000 vehicles with 14% heavy vehicles. The asphalt mix types used were asphalt concrete (AC) and stone mastic asphalt (SMA), and the used binders were PMB 60/120-60 and pen 70/100 bitumen. The surfacing mixes were tested both at the time of construction as well as afterwards in the laboratory with focus on resistance to deformation and wear. The field performance of the test sections was monitored yearly (2001-2010) by measurement of rutting and roughness development. Regular manual inspections were also conducted to observe the development of other distresses. The study concluded that, after nine years in service, the asphalt mixes PMB showed 40 % less rutting than the same asphalt formulation with unmodified 70/100 pen bitumen (Figure 20). The use of the PMB also improved the rutting performance of the asphalt surfacing layers that were produced with relatively low-quality aggregates.

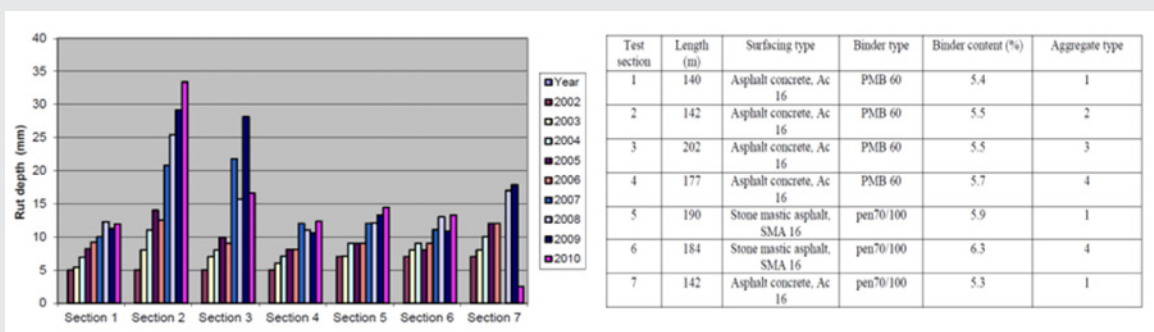


Figure 20. Field rutting measurements for the test sections; observe that section 7 was overlaid in 2010 (Saba et al., 2012)

In a later research program “Durable Roads” managed by the Norwegian Public Road Administration (NPR), performance testing of PMBs and benefit assessment of using PMB were addressed (Jørgensen et al., 2016). By a combination of laboratory testing and 14 field test studies on both AC and SMA mix types, it was reconfirmed that most of the selected PMB asphalt sections showed reduced rutting. The authors concluded that “according to the policy of using the asphalt wearing course that gives the best value for money, PMB is justified as a better choice than bitumen for most of the test sections”.

In a recent publication on the field performance of different asphalt surface layers under Norwegian conditions, six road sections of in-service times varied from 6 to 11 years were investigated (Zhang et al., 2024a). The asphalt surface layers of AC type were produced with PMB (pen 79, softening point 64.6°C) and unmodified bitumen 70/100. The binders were characterized by various physical and rheological measurements, as well as chemical analysis. It was found that PMB properties were less affected by service time and conditions compared to 70/100, demonstrating better durability of asphalt pavement containing PMB. In another paper by the same group, four two-layer structure road sections with service times ranging from 4 to 9 years were selected to study the effect of surface layer binder on the performance evolution of asphalt base layer (Zhang et al., 2024b). The asphalt surface layer was produced with the PMB and 70/100 bitumen mentioned above, whereas base layer was constructed with 160/220 bitumen. It was concluded that the binder type of the surface layer played an important role in base layer performance, and the use of PMB in the surface layer can not only prolong the lifetime of the surface layer but also mitigate deterioration of the base layer. This will result in a much longer service life on the asphalt pavement.



6. Statistical studies

A comprehensive analysis of field trials and comparative field data from USA and Canada was conducted by the affiliate committee of the Asphalt Institute (Asphalt Institute 2005, Von Quintus et al., 2007, 2008). Data from more than 30 different locations or trials with about 100 PMB test sections and appropriate companion sections were compared. Performance was assessed in terms of rutting, fatigue cracking, and transverse cracking. Various polymer types and concentrations and asphalt types were used in the sections evaluated. The polymers used included SBS, EVA, GTR, and various thermoplastic polyolefin types. Distresses measured on PMB and companion sections are shown in Figures 21 - 23. In addition to direct comparison of distress levels, mechanistic-empirical distress models were used to predict the increase in lifetime expected from PMB mixes. It was concluded that the use of PMB mixes result in less cracking and rutting – extending the service life of flexible pavements and overlays. On average, PMB wearing courses and binder layers exhibited about 50% of the cracking and 40% of the rutting measured on comparison projects with conventional mixes. In terms of service life, PMB asphalt mixes extended about 2 to 10 years over conventional unmodified asphalt mixes. Moreover, it was concluded that PMB asphalt mixes could reduce maintenance costs and the number of maintenance operations.

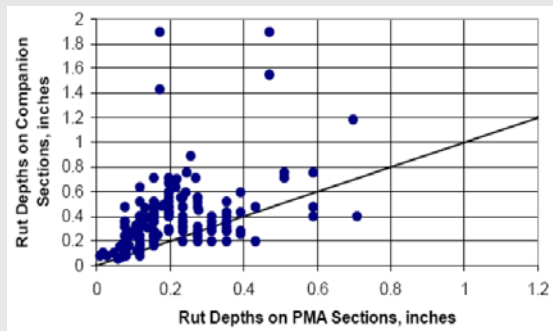


Figure 21. Comparison of the rut depths measured on sections with PMB and the companion sections without PMB mixes (Von Quintus et al., 2007)

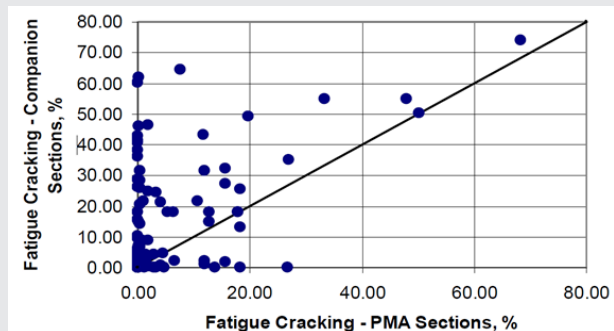


Figure 22. Comparison of the percent fatigue cracking measured on sections with PMB and the companion sections without PMB mixes (Von Quintus et al., 2007)

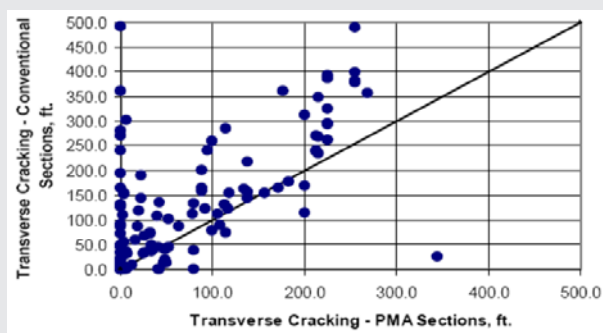
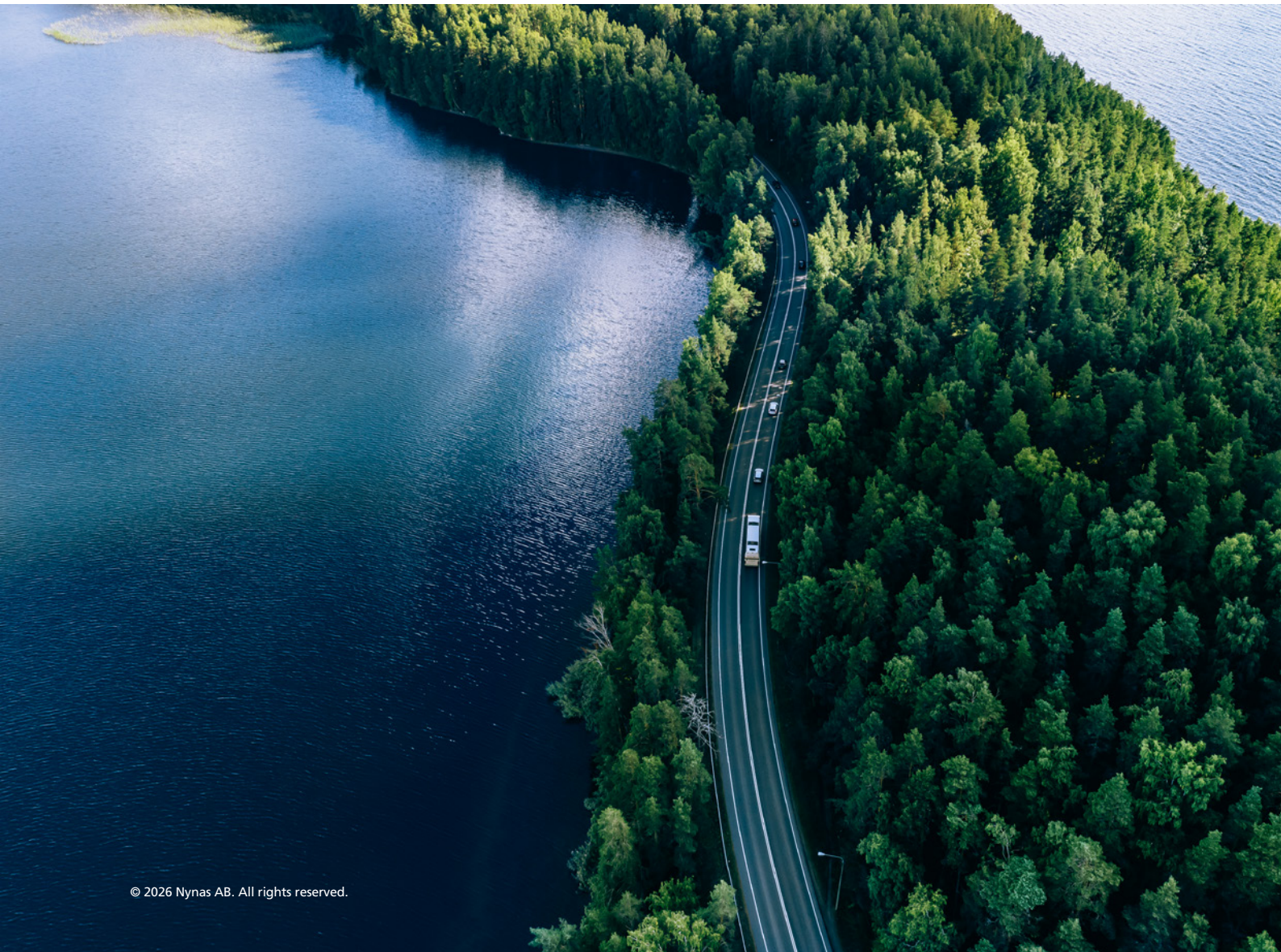


Figure 23. Comparison of the length of transverse cracking measured on sections with PMB and the companion sections without PMB mixes (Von Quintus et al., 2007)

In another statistical study recently carried out on the Swedish road network, a large amount of historical maintenance and road condition data (about 500, 000 records) from the Swedish Transport Administration's Pavement Management System (PMSv3) dating back the 1970s was analysed (Eklöf and Wendel, 2023, 2024). Road lifetime was estimated using survival analysis. To evaluate the effect of binders on road lifetime, the road's surface layer as well as the underlying layer were particularly studied. The roads were separated by binder type, such as unmodified bitumen and PMB. Road pavements with PMB were compared to equivalent roads with respect to 11 different variables, including annual average daily traffic, heavy vehicles, road type, road width, speed limit, construction year, region, bearing capacity, pavement type, stone size, and rut bottom distance. This study concluded that the use of PMB in the surface layer extended road lifetime by 15% and in the binder layer extended road lifetime by 8% as compared with the use of unmodified bitumen. When PMBs were used in both layers, the lifetime of the roads increased by 24% in comparison with unmodified bitumen in both layers. The survival analysis clearly shows a better pavement performance when using PMBs, but it is not a performance guarantee, considering other important factors such as choice of binder, pavement design and good workmanship.



7. Conclusions

PMB has been studied extensively for many decades, and beneficial effects are well demonstrated by various laboratory tests on binder properties and asphalt mix performance.

From field trials, PMB was found to improve long-term durability (aging resistance), fatigue life, and resistance to low temperature cracking. For permanent deformation / rutting resistance, differences between PMB and unmodified bitumen were not always obvious, especially when observation time was short (< 10 years); but there are field cases clearly showing advantages of using PMB. The performance benefits of using PMB was also shown when recycled asphalts were incorporated.

As for bridge applications, excellent field performance has been consistently observed.

Large scale statistical analyses indicate great benefits of using PMB in asphalt pavements. On average, PMB mixes extended the lifetime of asphalt pavements with about 2 to 10 years over conventional unmodified asphalt mixes In USA, while in Sweden the use of PMB in the surface layer extended road lifetime by 15% and in both surface layer and binder layer by 24% in comparison with unmodified bitumen.

The degree of performance improvement by using PMB depends on several factors, such as polymer type, binder composition, mix and pavement design, and workmanship. It should be noted that performance improvement is primarily seen when SBS polymer was used. EVA seems to be too plastic and thereby more sensitive to cracking. Evidently, to fully realise the benefits of PMB in sustainable road infrastructure development, proper material selection and quality control are of great importance.

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