Long Lasting Asphalt Materials with Highly Modified Asphaltic Binder

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Abstract On mature road networks, there is a constant need for long-term pavement preservation solutions. In the 1980s, SBS polymer brought a breakthrough technology with superior performance for surface layer. In more recent years, highly modified asphaltic binder, HiMA, took a step further for structural layers with fatigue resistance. At the same time, circular economy enhances the valorisation of Reclaimed Asphalt. However, its reuse in top layers is challenging, as RA may deteriorate cracking resistance. This paper presents results of laboratory evaluation of an asphalt mix combining 25% RA and the use of highly modified bitumen with 7.5% specific SBS polymer and compared with a same mix using a normal Polymer modified Bitumen 25/55-55. The evaluation was carried out with compactability, rutting resistance, complex modulus, fatigue and low temperature cracking susceptibility. From the mixes, binders were extracted and recovered for further evaluation similarly to the asphalt mixes. This study demonstrated the benefits of both standard PmB and highly polymer modified bitumen to achieve high performance asphalt mix combined with RA. The HiMA binder was able to restore, to a greater extend, the lost properties against cracking and still maintaining the benefits in terms of rutting resistance. This emphasises the benefit for PmB usage for both structural and surface layers, even when using Reclaimed Asphalt, for sustainable modern asphalt pavements.

Keywords Asphalt mix · Polymer modified Bitumen · HiMA binder · Pavement preservation

1 Introduction

The asphalt industry is continuously improving quality and performances of the asphalt materials to answer the increasing demand of traffic and user needs. In the 1980's Polymer modified Bitumen (PmB) was successfully developed to answer

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to the increase of traffic in volume and loading (Lu and Isacsson 1995). It is now commonly used for binder and surface layers. It enhances the rutting resistance and ensures durable surface integrity towards ravelling and surface cracking. In the last recent years, the use of highly modified bitumen, HiMA, were further developed for structural layers and rolled out over the world as the next step in pavement engineering (Habbouche et al. 2017).

The European commission has set up a road map for the implementation of circular economy in March 2019 (European Commission 2019) which reinforces the valorisation of any material at the end of its life. This is particularly valid for asphalt materials which are 100% reusable. However the usage in surface layers is still limited due to the risk of lost characteristics especially for cracking resistance.

When PmB is used in asphalt mix containing Reclaimed Asphalt (RA), there is a need to compensate the potential deficit of polymer network from the RA. With higher polymer content, HiMA binder offer the possibility to manufacture new asphalt mix containing RA similarly to high performance mix (Porot et al. 2019).

Recent development of Styrene-Butadiene-Styrene (SBS) polymer has made possible increasing polymer content in binder and still having stable bitumen for normal use at the mix plant. When blended with bitumen, SBS polymers, swell and increase by 5 to 10 times in volume. When increasing the polymer content, phase inversion occurs between a rich-bitumen phase to a rich-polymer phase. Usually at 5% the binder displays a balanced phase between bitumen and polymer, while at 7.5%, the polymer phase is predominant and the behaviour is more rubber like (Xia et al. 2016).

When increasing the SBS content in bitumen, the binder may be more difficult to produce with storage stability issues or higher viscosity leading to excessive mixing temperatures for producing asphalt mix. Special SBS grade, with high vinyl content, can mitigate these different potential drawbacks. It has a smaller size, which keeps the binder viscosity in reasonable range.

The concept of HiMA binder has been initially investigated by Delft Technical University in 2004–2008 (Molenaar et al. 2008). The outcomes showed that its use in structural layer can lead to substantial thickness reduction under a wide range of flexible pavement structures. Later the concept was validated in full scale experiment at the National Center for Asphalt Technology, NCAT, in the US and confirmed higher service life as compared to conventional binder, using the same designed asphalt mix (West et al. 2012).

This paper presents a comparative study between asphalt mix with 25% RA made with standard PmB and HiMA. It includes asphalt mix characterisation and also properties of the extracted and recovered binder from the mixes.

2 Experimental Plan

2.1 Materials

For the purpose of the study a highly polymer modified bitumen (HiMA) was compared with a commercial PmB, graded as 25/55-55. The HiMA binder was made with a 70/100 base bitumen and modified with 7.5% of special vinyl SBS polymer, D0243. This tailored SBS polymer is especially designed to have better compatibility with a wider range of bitumen sources and thus enables high concentration in bitumen. The structure and low molecular weight enable keeping the viscosity of the PmB at a reasonable level, limiting the mixing temperature to maximum 160–170 °C. The HiMA binder was graded as PmB 45/80-85 according to EN 14023.

2.2 Binder Testing

Binder testing was conducted on the original binders and on binders recovered from the mixes themselves. They were evaluated through conventional characterisation with penetration value at 25 °C and softening point temperature. The original binders were subjected as well to laboratory aging, with Rolling Thin Film Oven Test (RTFOT) and further with Pressure Aging Vessel (PAV). Fundamental testing was done using Dynamic Shear Rheometer (DSR) and Bending Beam Rheometer, BBR.

Binder Fatigue testing was also performed using DSR in repeated shear loading stress according to the RILEM protocol (Partl et al. 2013). The test consists of applying a cyclic shear load to a bituminous binder at different strain levels and recording the shear modulus. The fatigue life is determined when the remained shear modulus is equal to 50% of the initial value. In this study, to shorten the experiment, one strain level was used. The test was performed with an 8 mm plate, 2 mm gap at 10 Hz and 10 °C on the recovered mix binders.

2.3 Asphalt Mix Testing

The mixes used were an optimised AC 16 asphalt concrete mixture with a maximal aggregate size of 16 mm according to German specifications for binder layer application. They were both similar and contained 25% Reclaimed Asphalt (RA) with 4.8% final binder content. Table 1 shows the asphalt mix composition for both mixes.

The mixes were produced according to EN 12697-35 with the same mixing temperature of 170 °C and stored in an oven at 145 °C before compaction and testing.

Table 1 Asphalt mix formulation for AC16

Sieve, mm	0.063	0.25	2	5.6	8	11.2	16	22.4
Passing, %	5.4	9.3	25.1	44.8	51.0	63.6	97.8	100

Gyratory compaction was performed according to EN 12697-31. The specimen height is recorded along the number of gyrations and a curve of void content versus number of gyrations is derived. The test was carried out up to 400 gyrations to have a wide range of compactability, while usually a compaction at 60 gyrations is indicative parameter for binder layer to be laid in 6 cm thickness.

The resistance to permanent deformation (rutting) was determined using the German wheel tracking test (WTT) according to EN 12697-22 with a rubber wheel. The WTT was carried out at 60 °C for 10,000 cycles and rut depth recorded.

Stiffness modulus was measured by 4-point bending test, 4PBT, according to EN 12697-26, where a sinusoidal load is applied to beam at an initial strain level of 50 μstrain. The test, for each sample, was performed at four different temperatures ranging from −10 to +20 °C in frequency sweep from 0.1 to 30 Hz. This enables to produce master curves in a wide range of temperatures.

Fatigue performance was determined with the 4-Point-Bending Test, 4PBT, according to EN 12697-24. Initial strains were applied in a range of 125 to 250 μstrain at temperature of 20 °C and loading frequency of 10 Hz. The resulting stiffness modulus is recorded along the test duration and fatigue performance is determined when the modulus is decreased by 50% from the initial value.

Finally, the low temperature cracking susceptibility was evaluated through Thermal Stress Restrained Specimen Tests (TSRST) on prismatic samples, according to EN 12697-46. During the test, the specimen is kept at a constant length, while temperature decreases from 20 to −40 °C at a constant rate of −10 °C/h. With temperature decrease, the specimen shrinks. During the test, the force to maintain zero deformation is recorded and the induced stress is calculated, until the specimen breaks.

3 Results

3.1 Initial Binder Evaluation

A full evaluation on the original binder, as used later in the asphalt mixes, was made with empirical properties determined as per EN 14023 for PmB. Table 2 displays the main results. The HiMA binder combined very high softening point temperature and intermediate penetration value, still keeping the viscosity in a similar range, and at the same time having a higher elastic recovery. This results from the specific features of the high vinyl SBS used in the formulation.

Table 2 Empirical binder properties for both binders PmB and HiMA

Properties	Standard	Unit	PmB 25/55-55	HiMA binder
Penetration value at 25 °C	EN 1426	0.1 mm	42	56
Softening point	EN 1427	°C	58.4 °C	90.0 °C
Penetration index			0.28	5.90
Resistance to hardening Mass loss	EN 12607-1	%	0.13%	0.09%
Viscosity at 135 °C	EN 12595	mm^2/s	1510	2270
Elastic recovery at 25 °C	EN 13398	%	77%	98%

Table 3 Change of binder properties after lab aging for 20/30 and HiMA binders

	PmB 25/55-55		HiMA binder	
	Penetration value	Softening point (°C)	Penetration value	Softening point (°C)
Original binder	42 0.1 mm	58.4	56 0.1 mm	90.0
RTFOT	29 0.1 mm	63.6	41 0.1 mm	89.0
Change *	69%	+5	73%	−1
RTFOT+PAV	19 0.1 mm	71.2	26 0.1 mm	90.0
Change *	45%	+13	46%	0

*as compared to original binder

Aging was also evaluated on the binders for short-term and long-term aging conditioning with RTFOT, and PAV. Table 3 displays the changes of properties. Usually, bitumen ages by one grade harder through short term and further another one for long term aging. On the contrary, the HiMA binder did not show important changes in the properties; especially the softening point temperature hardly changed. However, it is worth noticing that RTFOT is not always best ad hoc test for PmB due to high viscosity that limits thin film formation in the bottle.

Furthermore rheological measurements were carried out. Shear moduli were measured using DSR in temperatures ranging from −30 to +90 °C at a fixed frequency.

Figure 1 displays the shear modulus |G*| vs. temperature. For a given temperature, the HiMA binder had lower values, less stiff, although for the high temperature range both binders displayed similar values.

Figure 2 displays the DSR results in Black Space with phase angle versus shear modulus.

The lower the phase angle is, the more elastic response the material has, which is a benefit at high temperature against permanent deformation. Both binders displayed a clear rubber plateau for low shear moduli, high temperature domain. It is more pronounced for the HiMA binder starting at 10^7 vs 3.10^5 Pa for the PmB, respectively corresponding to temperature of 10 and 40 °C.

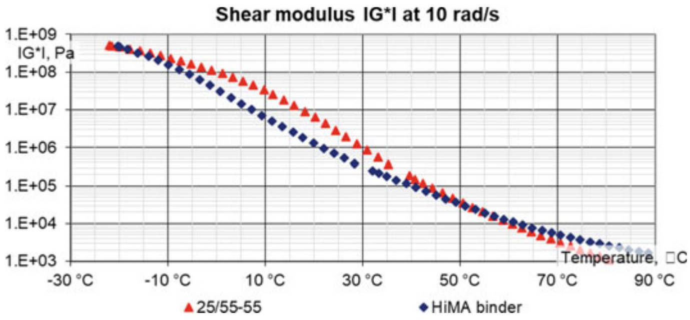

Fig. 1 DSR shear modulus results for both PmB and HiMA binders

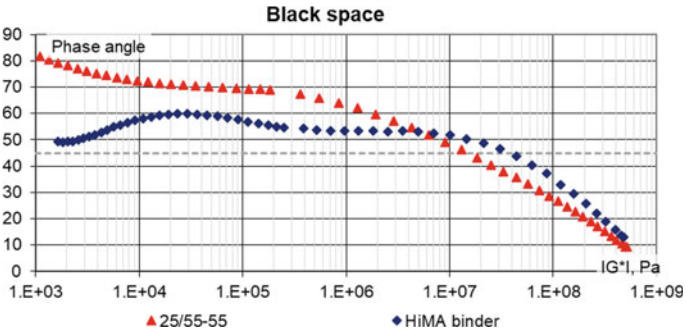

Fig. 2 DSR Black Space for both PmB and HiMA binders

Additionally, BBR was performed. This, in combination with DSR measurements, allows determining the PG grading of the binder. Table 4 displays the main criteria determining PG grading. The HiMA binder displayed a higher temperature PG, and at the same time a lower temperature PG, as compared to the 25/55-55 PmB.

Table 4 Results of PG grading for PmB and HiMA binder

	Criteria	PmB 25/55-55	HiMA binder
High temperature (original)	$\|G^*\|/\sin\delta \geq 1.00$ kPa	81.6 °C	97.3 °C
High Temperature (RTFOT)	$\|G^*\|/\sin\delta \geq 2.20$ kPa	79.5 °C	90.4 °C
Intermediate T (RTFOT+PAV)	$\|G^*\|\sin\delta \leq 5000$ kPa	25.9 °C	17.3 °C
Calculated intermediate T	(highT + lowT)/2 + 4	32 °C	34 °C
Low temperature BBR (RTFOT+PAV)	$S \leq 300$ MPa m-value ≥ 0.300	−15.7 °C −13.0 °C	−19.6 °C −20.1 °C
True PG		80–23	90–30
PG grade		PG 76-22	PG 88-28

3.2 Asphalt Mix Characterisation

Asphalt mixture characterisation was carried out following the European performance approach, in place for more than 15 years. It is based on compactability using the gyratory compactor, resistance to permanent deformation through WTT, and, for structural layers, mechanical characteristics with modulus and fatigue. While it is not mandatory, low temperature cracking susceptibility was also measured.

Compactability was addressed with gyratory compaction at 145 °C shown in Fig. 3. Despite different properties especially with higher softening point temperature for the HiMA binder, both mixes did not exhibit any difference in compactability and after 60 gyrations achieved void contents between 6 and 8%.

The resistance to permanent deformation was carried out through WTT at 60 °C. Figure 4 displays the results with the rut depth in mm vs. the number of passes. Both mixes performed very well with rut depth kept below 2.5 mm.

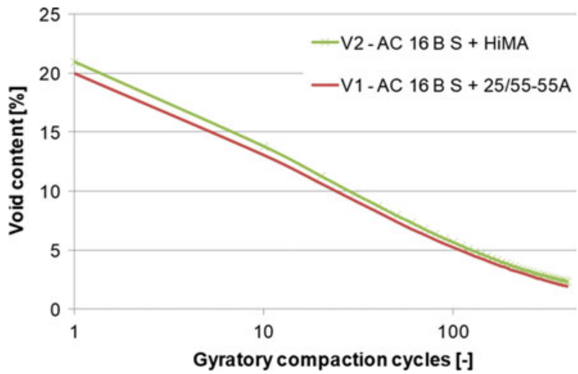

Fig. 3 Gyratory compaction for both mixes with PmB and HiMA binders

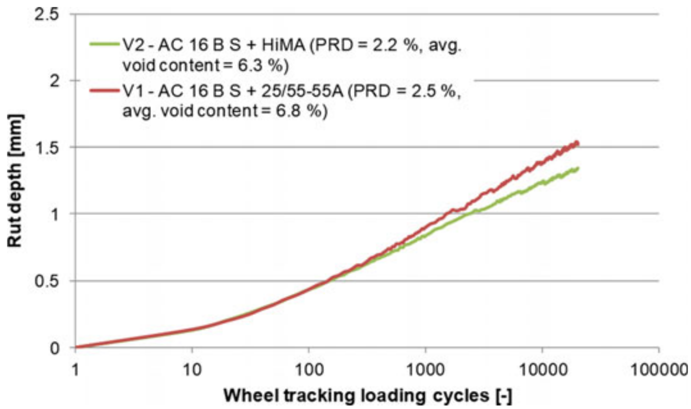

Fig. 4 Wheel Tracking Test for both mixes with PmB and HiMA binders

The mechanical characteristics were evaluated with stiffness modulus at different temperatures and frequencies and fatigue resistance at 20 °C and 10 Hz, with four point bending beam test.

For stiffness modulus, master curves were developed using sigmoid model and Arrhenius equation. Figure 5 displays these master curves at a reference frequency of 10 Hz. They both displayed high values, although slightly lower for the HiMA mix. At 20 °C in the range of 10,000 MPa, while standard asphalt mixes are more between 5000 to 8000 MPa. This may be a result of the use of the 25% RA in the mix.

Figure 6 displays the fatigue life curves for both asphalt mixes with strain level vs. number of cycles. For the same strain level, the number of repeated loading cycles was higher for the HiMA mix. With extrapolation of the curve, at one million cycles, the strain would be respectively 128 and 110 µstrain for the HiMA and PmB mix.

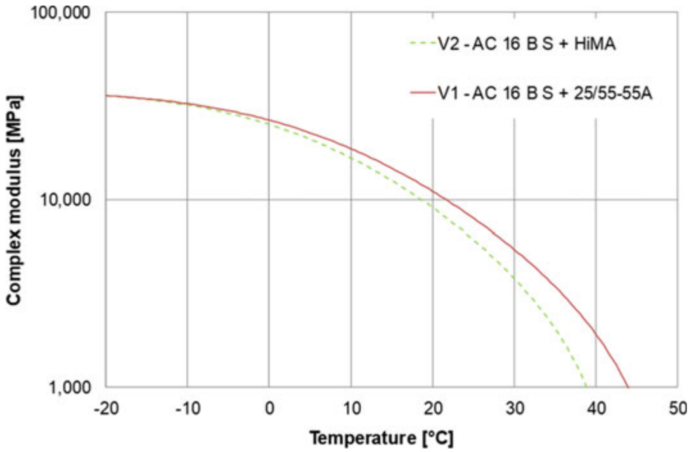

Fig. 5 Stiffness modulus for asphalt mixes with PmB and HiMA binder

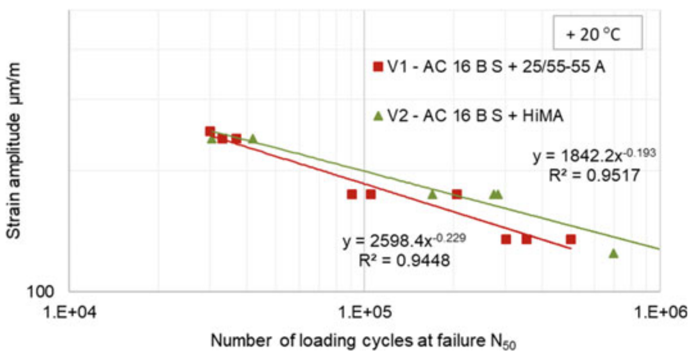

Fig. 6 Fatigue life for asphalt mixes with PmB and HiMA binder

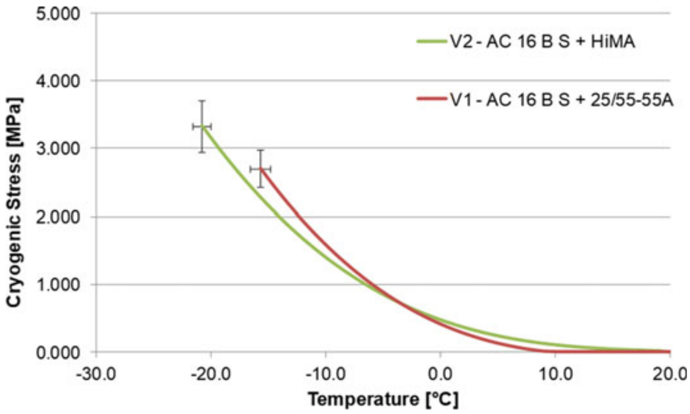

Fig. 7 TSRST results for mix with PmB and HiMA binder

Finally, the low temperature cracking susceptibility was assessed with TSRST, on three replicates for each mix. Figure 7 displays the results of the mean value of each mix in terms of stress curve vs temperature, the error bars being for min and max of failure values. The HiMA mix showed the lowest failure temperature as compared with the PmB mix. This is consistent with the binder evaluation where the HiMA binder had the best performing low temperature PG grading.

3.3 Recovered Binder Evaluation

From the asphalt mixtures, the binders were extracted and recovered according to EN 12697-3 and further tested. In addition to conventional characterisation, fundamental testing was performed and only discussed below. It is worth to notice that the mixes had 25% RA, which affected the recovered binder. RTFOT aged binders were compared with recovered binders and the original binders being for reference.

DSR measurements were investigated via the Black Space, and displayed in Fig. 8. For each binder, the curves overlapped with a contraction from left to right. The rubber plateau remained either after RTFOT or from the recovered mixes. There is a slight change in the shape, the curvature of the curve, between RTFOT and recovered binder, this is most likely due to the presence of RA binder in the latter.

In addition to DSR test, binder fatigue test was performed at 10 °C with repeated shear loading. Figure 9 displays the percentage of remained shear modulus vs. the number of load cycles at same strain level of 1.3%. For the PmB, after a slight increase of the shear modulus, it decreased after 3.10^4 cycles. With the HiMA binder, the shear modulus slowly continuously decreased but without reaching the 50% criteria.

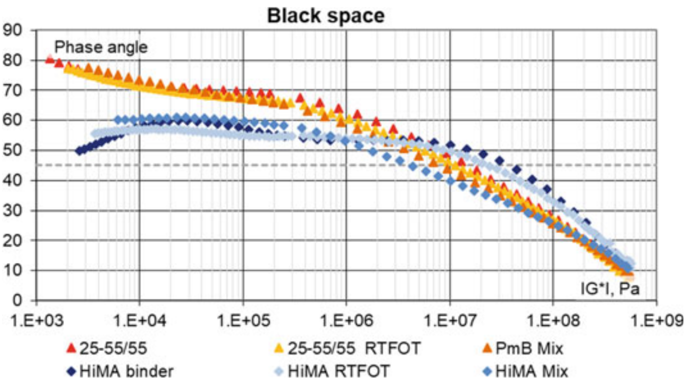

Fig. 8 Black space comparison of fresh and recovered binders, HiMA and PmB mixes

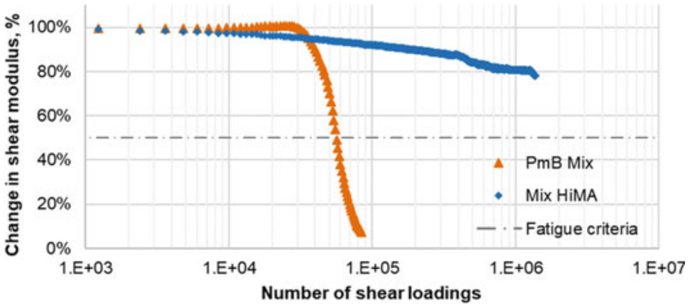

Fig. 9 Binder fatigue life for the recovered binder from PmB and HiMA, change in shear modulus

4 Conclusion

The asphalt industry is continuously developing solutions to address the current and future needs of road network. Polymer modified Bitumen, developed 40 years ago, has addressed the need for increased traffic, in volume and load. The European Commission is implementing Circular Economy across all industries. This implies for road mature network the necessity to reuse more Reclaimed Asphalt into surface layer.

The use of highly modified bitumen in combination of RA in asphalt mix can mitigate the potential risk of premature cracking failure.

This study focused on the comparison of standard PmB and HiMA binder in asphalt mixtures with 25% RA. Asphalt mix results showed that both can mitigate potential cracking risk either fatigue or thermal without compromise in rutting resistance. The HiMA binder offered even better cracking resistance than standard PmB.

The evaluation carried on the binder with fresh and recovered binder from the asphalt mixes have shown the effect of polymer modification and were consistent with mix characteristics. The HiMA binder demonstrated higher performance either on pen grading system or PG grading system with broader temperature interval. Fatigue testing on recovered binders showed that the HiMA binder displayed very long life spam.

Overall, it is possible to reuse 25% RA in asphalt mix for surface layer application with polymer modified bitumen without compromise on cracking and rutting. The use of HiMA offer an even better solution maintaining reasonable modulus and ensuring lower cracking susceptibility.

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