Polymer modified bitumen sustainable and circular

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Polymer modified bitumen a key component for sustainable asphalt

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Summary

Motorized traffic has increased significantly since the first asphalt roads were built in the last century. The growing and increasing heavy traffic, especially from trucks and the rise of electric vehicles, means that a standard asphalt pavement is no longer adequate in many cases. As a result, the pavement often shows premature raveling, rutting or cracking. In such situations, polymer modified bitumen (PMB) offers a solution. In addition, for thin (porous asphalt) wearing courses, standard bitumen is often found to be of insufficient quality, so PMB is applied in these types of pavements.

Bitumen modifications have been experimented with for quite some time. Initially with crushed rubber from used tires. Nowadays, thermoplastic elastomers such as styrene-butadiene-styrene (SBS) and plastomers such as ethylene-vinyl acetate (EVA) are mainly used as modifications for PMBs. The degree of modification depends on local (project) specifications. The main advantages of PMB are better properties at high temperatures with better resistance to rutting, better adhesion properties that reduce raveling and lower temperature sensitivity that offers better resistance to climate change.

Application of PMBs does not prevent reuse of polymer modified asphalt (PMA). Extensive research into this was already carried out in the late 1990s and concluded that using PMA recycled asphalt granulate (PMB RAP) gave the asphalt more favourable properties than using unmodified recycled asphalt granulate. However, special attention should be paid to relatively fresh PMA granulate. Recent developments show that horizontal recycling of PMA granulate from wearing courses into new wearing courses is possible without loss of quality.

It is also possible to apply polymer modified bitumen (PMB) when used as warm mix asphalt (WMA). Research since 2002 has shown that PMB can be used successfully with current WMA techniques. It is important to choose a PMB specifically suitable for use in a WMA asphalt mixture. By combining this with reuse, a sustainable asphalt can be obtained that is safe to process with a long service life and the lowest cost per life year. All in all, polymer modified bitumen offers a proven technology as a more sustainable, efficient and economical road management solution.

Keywords: Polymer modified bitumen (PMB); polymer modified asphalt (PMA), circular, warm mix asphalt (WMA), recycled asphalt granulate (RAP).

1. Introduction

Since the early 1980s, polymer modified asphalt (PMA) has been used on many large and small projects worldwide. In many countries today, the use of PMA is even prescribed for heavily loaded road structures. Polymer modification is also indispensable in (porous) thin noise reducing overlays (thin surfacing's). Thanks to the application of PMB, thin surfacing's have an acceptable lifespan and therefore thin surfacing's have a right to exist. A PMB is therefore indispensable in asphalt for heavy-duty applications and/or ensuring a long service life.

A PMA also reaches the end of its service life and must then be removed. Questions are raised in the market whether polymer modified asphalt (PMA) can be reused as partial recycling (RAP) in new asphalt. In practice, the reuse of the old PMA granulate appears to be perfectly possible but it is necessary to carefully and competently examine what (positive) properties this old asphalt still has. Recent developments show that horizontal recycling of (polymer modified) porous asphalt and SMA granulate can make a significant contribution to achieving road authorities' objectives of achieving more sustainable asphalt mixtures while retaining their original properties.

Warm mix asphalt (WMA) is possible in combination with a PMB. Together with partial recycling (RAP), this can achieve optimally sustainable asphalt with low costs per year of service life. This fits into the transition path to sustainable asphalt paving. A PMB contributes to circularity and sustainability in construction. Its compatibility with warm mix asphalt techniques, such as foaming, enables production at lower temperatures, reducing energy consumption and emissions. PMB is recyclable and can be reused in future projects, reducing waste and saving the use of primary raw materials.

This paper will elaborate on the benefits of applying a PMB and aspects related to the possibilities of applying a PMB in combination with recycling and warm mix asphalt.

2. Why use polymer modified bitumen

The use of polymer modified asphalt (PMA) with a polymer modified bitumen (PMB) is now common in heavily loaded pavements. The advantages of a PMA are (depending on the polymer modification) that the asphalt lasts longer and/or can be applied in a thinner construction/structure. PMBs are also commonly used for thin noise-reducing overlays (thin surfacing's). With modification, these overlays meet the desired requirements with current traffic loads.

Depending on the degree of modification, the benefits of a PMB are:

- Improvement in rheological properties of a bitumen and thus the asphalt.
- Improvement in rutting resistance.
- Improvement in fatigue and cracking resistance.
- Improved adhesion properties against raveling.
- Improved temperature sensitivity, resulting in longer service life and better resistance to climate change.
- Layer thickness reduction.
- Fully recyclable.
- Applicable in combination with partial recycling of RAP.
- Possible in combination with warm mix asphalt.

2.1 Modification PMB

Standard penetration bitumen is obtained from the residue of crude oil distillation. In a refinery, crude oil is distilled into different fractions and the refinery will try to choose crude oils - or blends of crude oils - that are most economically viable for its operations. Depending on the crude oil's origin, it is more or less suitable to produce the desired petrochemicals [1].

Chemically, bitumen is a very complex product. Therefore, this chemical structure depends on the origin of the crude oil and the refinery. Even if these bitumen are similar to each other according to current standards (according to European standard EN 12591). The quality of standard bitumen can therefore differ, which can affect the performance of the asphalt produced.

Since the first construction of asphalt roads in the late 19th century, bitumen modification has been experimented with to improve its properties. Initially, recycled rubber was used. Since the 1970s, synthetic polymers were mainly used.

The most commonly used polymer modifications for a PMA are the SBS (Styrene-Butadiene-Styrene) polymer and, to a lesser extent, the EVA (Ethylene-Vinyl-Acetate) polymer [2]. These polymers are well compatible with bitumen, allowing a homogeneous blended product to be obtained. Both polymers have specific properties and can be used separately or combined in a PMA depending on the desired properties and any national specifications [3]. Which polymer is applied can usually be characterized by FTIR (Fourier Transform Infrared spectrometer) analysis of the recovered bitumen (see Figure 1). The intensity of the peak in the FTIR curve is a measure of polymer modification. Depending on the age of the PMA, the effectiveness of the polymer will decrease over time. To what extent the effectiveness decreases depends, among other things, on the initial modification and the asphalt type.

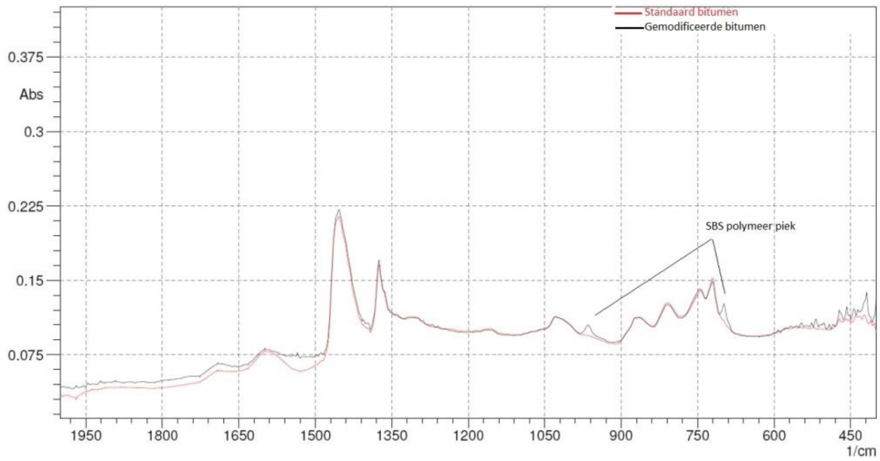

Figure 1: Example FTIR analysis of a (modified) bitumen recovered from asphalt granulate.

PMBs are classified in Europe according to the European standard EN 14023. This standard describes a framework of bitumen properties. Depending on local regulations, specifications are drawn up for application in asphalt. How a PMB acts depends on the severity and type of modification. This often makes it difficult to compare one type of PMA with another. Traffic load and type of asphalt also play a role. Asphalt on a very heavily loaded road is more likely to fail than when exposed to lighter loads. In other words, the fatigue properties depend on the imposed strain/load, the lower the load the higher the service life.

With SBS polymer modified bitumen, great savings on the layer thickness of the asphalt pavement are possible above a certain minimum modification level with an equal or even longer service life than a conventional asphalt pavement [4].

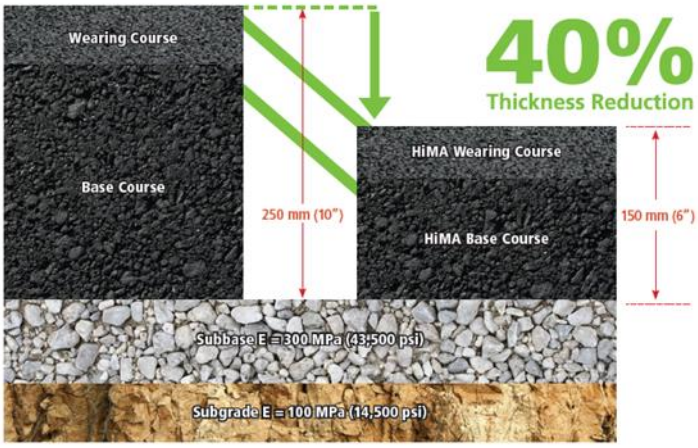

Figure 2: Example construction with layer thicknesses of the reference section and the section with highly modified asphalt.

Also, a PMA as an interlayer offers advantages in preventing reflection cracking from the substrate. The tough properties of highly modified PMBs slow down crack growth from below. Which results in a longer service life of the asphalt pavement.

3. Circularity PMB

Asphalt is widely reused in the Netherlands in the form of partial recycling of RAP in new asphalt. Recycling can be applied with standard asphalt as well as with old polymer modified asphalt (PMA) without problems and without much effort, up to percentages of 60-70% RAP for sub-bases (AC bin/base asphalt). To date, the obtained quality of the new asphalt is at least comparable to the quality of standard asphalt without RAP.

An important factor in the quality of asphalt with a high RAP content is the quality and pre-treatment of the asphalt granulate. The quality depends on the asphalt layer (grading and bitumen content) and degree of contamination in this layer during road milling. Fractionating and sorting (by property, such as type of crushed stone and bitumen content) the asphalt granulate improves its usability and allows higher percentages of RAP to be achieved (also in overlays) of new asphalt.

3.1 Research and practice

As early as 1997, research was conducted into the environmental aspects of old PMA Porous Asphalt granulate [5]. This study showed that the emission of PMA granulate was at the same level as unmodified asphalt granulate. This should also be expected, as the chemical structure of the polymers used (EVA or SBS) is not chemically different from components from which bitumen is composed. Applications abroad, for example in Japan, showed potential with Porous Asphalt made with PMB. They have been reusing RAP for more than 30 years, up to 80% RAP in new PMA, even in some cases for the second or third cycle [6].

The change of properties of a PMB during ageing, through production and during service life can be simulated in the laboratory on the binder by the Rolling Thing Film Oven Test (RTFOT) (short term ageing) and Pressure Aging Vessel (PAV) (long term ageing) on the one hand and on the asphalt mixture to simulate accelerated field ageing on the other hand. Experiments conducted in the laboratory when comparing unmodified bitumen, PMB and even highly modified PMB have clearly shown that PMB has less properties-change than the unmodified bitumen, as shown in Figure 3 [7]. This can be attributed to the fact that during PMB processing at high temperature, the base bitumen acquires thermal stability.

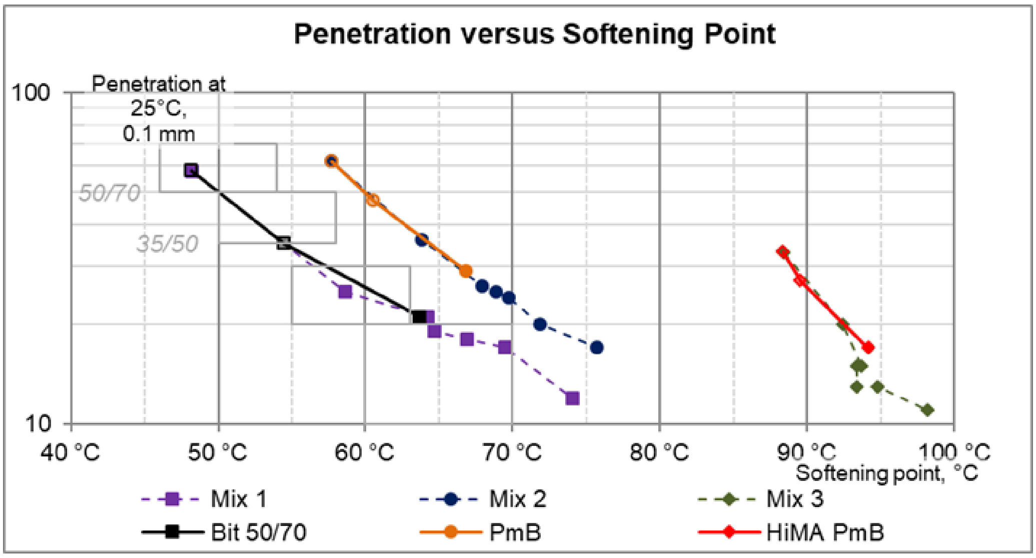

Figure 3: Change of binder properties in the asphalt mixture when comparing conventional bitumen versus PMB [7].

Also in 1997, research was carried out by the Dutch road authorities laboratory (DWW) in Delft on a highly stable asphalt mixture (AC 22 base) using 40% old PMA Porous Asphalt granulate. This study concluded that by using PMA RAP, the AC base mixture had more favourable fatigue properties and higher resistance to permanent deformation than when using unmodified RAP [8].

In 2005, an improved version of the aforementioned AC 22 base with 40% RAP (PMA granulate) was applied on the A12 junction Grijsoord – Waterberg highway, where the fresh bitumen component was also a polymer modified bitumen. This mixture was intensively examined during production and processing. In the process, no problems were observed during its construction [9].

European research from 2013 [10] shows that PMA granulate is a valuable building material to reuse. In this 2-year European study, the potential of PMA granulate was investigated on a laboratory scale. The study showed that PMA granulate still contains an active polymer content, which can be used positively in new asphalt mixtures. However, this requires the PMA granulate to be properly homogenised and characterised to (optimally) exploit its benefits.

Research has also recently been conducted to be able to restore the original properties of PMB binder using a rejuvenation technology. This is being done to enable horizontal recycling of PMA so that the high-quality PMA granulate is fully and effectively utilised instead of depreciating in value. This can be achieved if the PMA granulate can be selectively milled for recycling [11,12].

Reuse of PMA granulate is thus proven in theory and practice. However, special attention should be paid to PMA granulate that was in the road for less than about 1 year (demonstrable by e.g. weighing receipts). This PMA granulate may have properties (such as a high viscous behaviour) that prevent it from being mixed through a parallel drum system commonly used in the Netherlands at 120 to 130°C. Such PMA granulate should therefore be homogenised beforehand with unmodified asphalt granulate. It should be borne in mind, however, that milling fresh PMA is of course a rare and infrequent situation.

The use of PMA granulate also has added value for heavily loaded structures. In 2021, the Polderbaan (Runway 18R/36L) at Schiphol Airport was successfully renovated with 60% recycled asphalt derived from the old PMA asphalt layers combined with new PMB bitumen [13].

3.2 CE-asphalt

As mentioned earlier, any modification of the asphalt granulate affects the new asphalt properties. This is also noticeable in CE asphalt type tests. An asphalt mixture with PMA granulate will have significantly different (better) properties as a result (depending on the modification). Table 1 shows a possible effect of using PMA granulate as an illustration.

Table 1: Example effect PMA granulate on asphalt properties AC 16 surf 40/60 (40% RAP).

Asphalt properties	Standard RAP	PMA RAP	Dimension
Water sensibility **ITSR**	98	103	%
Stiffness $\mathbf{S_{mix}}$	7200	6970	MPa
Resistance against deformation f_c	0,22	0,08	μm/m/s
Resistance against fatigue $\boldsymbol{\varepsilon_6}$	132	213	μm/m

In particular, fatigue resistance can be greatly increased by applying a PMA granulate. In addition, adhesion properties are improved with a PMB. This improves water sensitivity. A study conducted at TU Delft, including 3D damage modelling and experimental tests on the binder to simulate winter damage, demonstrated the benefits of a PMB compared to standard bitumen [14].

For a standard asphalt type test with unmodified asphalt granulate, it is wise to investigate that the asphalt granulate to be used is indeed unmodified (through FTIR analysis of the recovered bitumen). This is to keep the results pure.

3.3 Hybrid asphalt mixtures

Combining a (heavily modified) PMA with 50% RAP (standard sub-layer RAP) creates a so-called hybrid asphalt mixture with superior properties compared to a conventional AC binder/base asphalt mixture, making it possible, to reduce the total layer thickness with the result that the total environmental impact (Environmental Cost Indicator (ECI)) is thereby reduced (lower ECI per m^2 asphalt). By applying 50% RAP, there are no special requirements for the asphalt granulate and this type of asphalt can be produced relatively easily in almost any asphalt plant. Attention should only be given to the minimum amount of PMB to be added. The following case study (A4 Steenbergen) elaborates on this.

In September 2012, an AC 22 base/bind hybrid asphalt mixture was applied on a large scale for the first time on the newly constructed A4 highway near Steenbergen. By applying this mixture, 50 mm thickness of asphalt could be saved on this project (based on construction calculations). So besides reusing material, savings were also made on new raw materials. Table 2 shows the raw material savings on the project.

Table 2: Material savings in application of hybrid asphalt mixture A4 near Steenbergen.

Principles:		
Length of road approx.	12	km
Width of road approx.	25	m
Surface area approx.	300000	m^2
Density AC bind/base	2360	kg/m^3
Density Porous Asphalt	2000	Kg/m^3
Lifetime (mechanical properties) are the same for all construction.		

Standard design construction	**Thickness mm**	**Amount mton**	**kg CO_2 / ton**	**Total**	
Porous Asphalt (DZOAB)	50	30000	67,13	2014	(industry average)
AC 22 base/bind 40/60 (50% PR)	60	42480	36,32	1543	(industry average)
AC 22 base/bind 40/60 (50% PR)	65	46020	36,32	1671	(industry average)
AC 22 base/bind 40/60 (50% PR)	70	49560	36,32	1800	(industry average)
AC 22 base/bind 40/60 (50% PR)	70	49560	36,32	1800	(b industry average)
Total		**217620 ton**		**8828**	**ton CO_2**

Applied construction	**Thickness mm**	**Amount mton**	**kg CO_2 / ton**	**Total**	
DZOAB	50	30000	67,13	2014	(industry average)
AC 22 base/bind 40/60 (50% PR)	65	46020	36,32	1671	(industry average)
AC 22 base/bind 40/60 (50% PR)	80	56640	36,32	2057	(industry average)
AC 22 base/bind SFB 5-50 (HT) (50% PR)	70	49560	41,48	2056	(Asphalt plant APRR)
Total		**182220 ton**		**7798**	**ton CO_2**

Reduction (by thickness reduction)	35400	ton asphalt	1030	ton CO2
	-16%		**-12%**	

CO_2 emissions per tonne of asphalt are higher for a hybrid asphalt mixture than the standard mixture without polymer modification. However, because less asphalt is needed (for the same structural service life), a cost-effective construction is still obtained with a lower environmental impact. Added to this are the savings in transport and processing time of the asphalt. When comparing standard asphalt mixture with standard bitumen, an asphalt mixture with PMB and a hybrid asphalt mixture with highly modified bitumen combined with 50% RAP, the difference in CO_2 footprint ex-factory is higher for the mixture with PMB, but the asphalt mixture with 50% RAP and PMB is already 11% lower (see figure 4) [15].

For a good comparison of the environmental profile of an asphalt mixture, it is important to consider it per quantity required in the construction and not per tonne of asphalt. So, for example, per m^2 per year of service life.

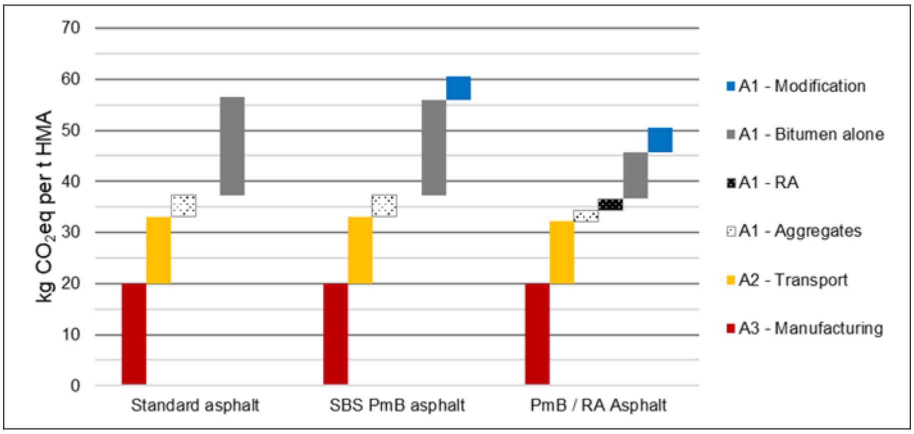

Figure 4: Consideration CO_2 footprint per ton of asphalt ex-factory different asphalt mixtures [15].

3.4 Horizontal recycling

Horizontal recycling of (polymer modified) Porous Asphalt and SMA granulate can make a significant contribution to achieving road authorities' goals of achieving more sustainable asphalt mixtures. In standard AC mixtures, Porous Asphalt/SMA granulate is used sporadically and only in small quantities. However, large batches of Porous Asphalt/SMA granulate cannot be used, while the granulate consists of a high-quality crushed stone and filler and (polymer modified) bitumen-rich mastic. A higher-grade application of Porous Asphalt/SMA granulate in new porous asphalt and SMA overlays thus offers many advantages. Application of more asphalt granulate scores favourably in the context of circular economy, cost savings and lower environmental impact.

By optimising the sieving process, it is expected to be possible to minimise material loss. This by, for example, sieving all Porous Asphalt granulate to 3 mm. How sieving can best be carried out depends on the possibilities at the asphalt plant. Asphalt banks are a solution to the availability of suitable Porous Asphalt and SMA asphalt granulate. By properly fractionating and screening this makes it possible to also produce Porous Asphalt and SMA overlays with at least 60% RAP.

For optimal recycling of PMA granulate from wearing courses in a new wearing course, it is desirable to restore the original polymer network. Studies by TU Delft and others show that it is possible using a PMB with a rejuvenating effect [14, 16].

4. Warm mix asphalt

The favourable effects of warm asphalt mixtures (WMA) prompted the members of Dutch branch association for bituminous works (VBW) to qualify WMA as the new standard and to have phased out the production of hot asphalt mixtures (HMA) for road construction asphalt by 2025.

Since the beginning of this century, several methods of applying WMA have already been tested in the Netherlands. In these, WMA is a warm asphalt mixture mixed between 100 and 140°C. These methods are briefly listed:

- Foaming techniques
- Viscosity-changing additive
- Zeolites
- Chemical (bio)additives

The methods mentioned all have their pros and cons. Only a viscosity-modifying additive such as a wax, for example, changes the properties of the bitumen. A modified bitumen is then obtained, as it were, with changed properties (lower penetration and higher softening point). In the other methods, the original bitumen properties remain the same. The effect in these methods relies on better wetting (lubricity) in asphalt production.

By a specific choice of modification of a PMB, a PMB suitable for processing as WMA can also be obtained. Practical trials in Germany have shown that this is possible [17].

5. Health aspects PMB

Health and safety are paramount in all industries, including the infrastructure sector. Because asphalt mixtures are made at elevated temperatures, fumes are released that can affect worker exposure limits. Due to its higher viscosity, PMB may require a higher mixing temperature than standard asphalt bitumen. This may raise the question of the impact on bitumen fumes released during production of PMB itself, binder processing and production at the asphalt mixing plant.

Experiments were conducted to evaluate the vapour emission of PMB compared to standard bitumen and more specifically the volatile organic compounds (VOC) and polycyclic aromatic hydrocarbons (PAH) [18]. It confirmed that the VOC level is strongly dependent on temperature. However, when compared at the same temperature, PMB showed lower VOC levels by a factor of 2 to 10 (Figure 5). The possible explanation is that during PMB processing, the bitumen is already heated at elevated temperature and the most volatile components have already been released and treated with exhaust gas cleaning during PMB production. This indicates that during PMA processing, emissions can remain below the limit. Applying WMA techniques will further reduce vapour emissions.

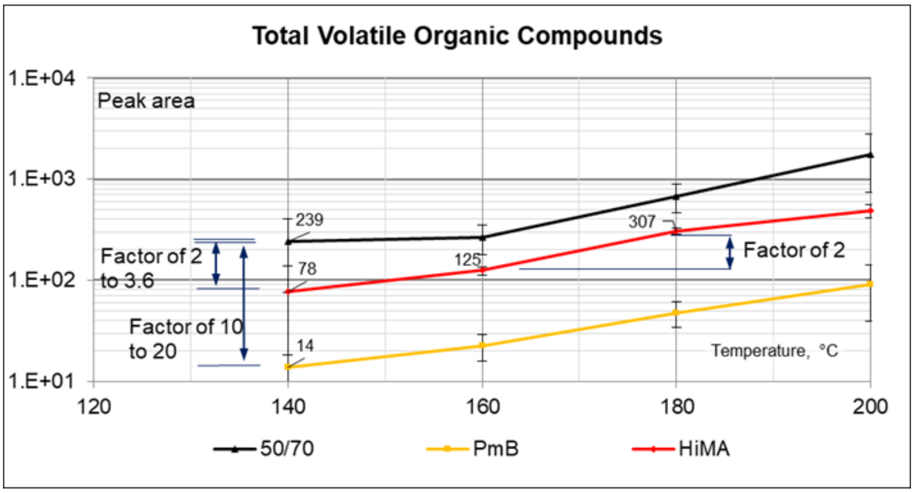

Figure 5: Total VOC content versus temperature for standard bitumen, PMB and highly modified PMB.

6. Conclusions

The use of polymer modified bitumen can contribute significantly to improving the properties of asphalt. This manifests itself in increased resistance to cracking and permanent deformation, contributing to a longer service life of the asphalt.

Polymer modified asphalt with a polymer modified bitumen is fully circular and can be processed as warm mix asphalt (WMA). Applying a PMB therefore fits within the transition path of sustainable asphalt paving.

By applying a PMB, the service life of an asphalt pavement can be extended and/or layer thickness reduction can be applied. This results in a lower environmental cost index (ECI) per m^2/year of the asphalt construction (favourable total cost of ownership). With a high-quality polymer modified bitumen, it is therefore possible to reliably and cost-effectively achieve the sustainability goals of the construction industry with minimised risk.

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