DURABILITY STUDY: FIELD EXPERIENCE OF LONG-TERM EVOLUTION OF SBS POLYMER MODIFIED BINDER

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ABSTRACT

The polymer modified bitumen (PMB) has been used for decades as solutions of rutting and cracking problems generated by significant increases in heavy traffic. Experiments in laboratories and in situ observation over several years demonstrate the excellent characteristics of these products.
A comparative experimental study on the highway A9 near Sion in the canton of Valais was conducted between 1988 and 2002. Throughout the study, an intense campaign of monitoring the surface conditions and laboratory tests on materials was realized on 16 comparatives sections of 300 m made with commercial binders. Samples were collected at various times during the life time of the highway. Very good performances were observed for the section 11. At the same time a section of 4 km was established with the same SBS modified binder (section 11a) which remained in service until 2009. The surface layer was removed after 21 years of service.
This paper focuses on the long term behavior which is different depending on the binder type, significant discrepancies are observed thru a wide range of laboratory tests (TSRST, BBR, modulus, fatigue, recovered binder characterization). The test results are correlated with observed sections surface distresses.
The comparison has highlighted the exceptional strength of the section constructed with crosslinked SBS modified bitumen in comparison with conventional bitumen.

Keywords: Field experience, aging, long-term performance, polymer modified binder

1. INTRODUCTION

Polymer modified bitumens (PmB) have been in use for many years as solutions to rutting and cracking due to significant increase of heavy goods vehicles on the motorway network. Experiments carried out in the laboratory and on site have developed over the years, proving that PmB are extremely efficient.
In the 1980s, many PmB and additives appeared on the Swiss market. The team of experts from the VSS (Swiss Road and Transport association) believed that a standard was soon necessary to define the technology and speed up its development and use [1]. Seeing however that experience was limited both in the laboratory and in situ, this committee put forward the proposal of testing out their ideas on the A9 motorway near Sion in the Valais district [2], [3]. In 1988, tests were carried out on a section of this motorway which was under construction and on 16 individual comparative test sections, each measuring 300m [4]. Twelve were built by companies and were representative of products marketed in Switzerland including section 11 using Styrelf 13/80, a 3% crosslinked polymer bitumen (SBS) prepared under a special process by Elf (now Total). Four sections were built using pure penetration bitumens of grade 50/70 and 80/100. A 4km section (labelled N°11bis) was installed using the same binder as section N°11 [5].
A major campaign to monitor surface conditions and to test materials was launched. Positive feedback was given for the comparative sections after 14 years and for the 4 km section after 19 years. Samples taken at different stages in the motorway's life span and stocked in a controlled atmosphere allowed this study to be carried out.
In 2002, after 14 years of service, 16 sections were replaced as several showed signs of unacceptable damage (figure 1). The 4 km section was repaved in 2009. The efficiency of these products is significant. The Styrelf 13/80 polymer modified bitumen is examined in more detail below. It proved to be particularly effective in situ and in the laboratory.


Figure 1: Road surface comparison between 2 sections after 14 years of service : highly degraded section (left) and section N°11 in good condition (right).

After detailing the site conditions, that paper sums up the observations made on the 16 comparative test sections over the 14-year-long initial study. A focus on the 80/100 and Styrelf 13/80 from TOTAL allows the comparison of durability performances between pure and polymer modified binder. Finally traffic influence is delved into with some insight into the wearing course aging gradient.

2. SITE CONDITIONS

Performance evaluation of the binders is based on the same conditions for all. They were all applied on the same surface structure in identical setting and compacting conditions. They were subjected to the same traffic and climatic constraints.

2.1 Traffic pressure

The particular section of the A9 motorway under review has mainly seasonal tourist transport with an average annual number of 24000 vehicles per day between 1988 and 2007. The rate of traffic increase is 2.9% and heavy goods vehicles (HGV) only represent 6% of the overall traffic. The weight of traffic corresponds to 830 equivalent weights of standard vehicle axles weighing 80 kN, or a T4 traffic type in Swiss classification terms.

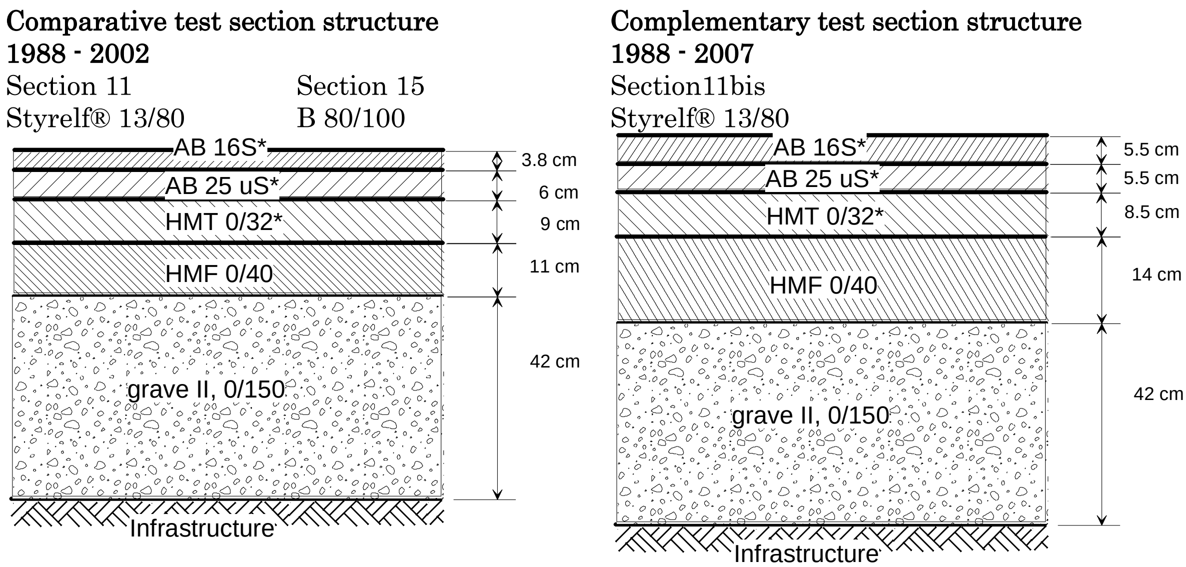
2.2 Climate

A specific weather station situated near the section has provided data concerning climate since 1992. Meteorological instruments include temperature sensors placed in the surface structure at different depths, a humidity sensor and a radiometer which measures visible and infrared solar radiation. The area under review shows climatic conditions which are typical of the Valais region (alpine valleys), notably long periods of sunshine (270 days per year and temperatures of over 30 °C on a regular basis), extremely cold conditions (under -10 °C) and days with very quick cooling-down speeds (5 °C/h). For the record TSRST is performed at -10°C/h [6].

2.3 Road surface structure

The surface layer concerned is made up of a standard bituminous concrete 16 S surface coating, which is 4 cm thick. The binder content and the thickness of the wearing course are identical for all products. Pavement design is illustrated on figure 2: 33 cm of bituminous material, all resting on a foundation layer composed of 42 cm of 0/150 gravel. Deflection measurements using a Falling Weight Deflectometer (FWD) showed very high bearing capacities and a structural life span well above the 20 years forecast when the surface was being laid.

Sections 11 and 11bis were laid at the same time in identical compaction conditions and on the same structure (figure 2). Only surface layer thickness varied. Separated by some hundred metres, they were subjected to the same traffic and climatic pressures.



* Sieve diameters ∅ according to old standard SN 640 431 (1976)
With: AB 16S, AB 25 uS, HMT 0/32, HMF 0/40 being dense asphalt concretes designed according to old Swiss standards in use at the time when the sections were implemented. Grave is unbound crushed gravel material. Numbers represent nominal aggregate sizes in mm.

Figure 2: Structure and foundation of the highway (test and complementary section)

3. SURFACE DISTRESSES AND LABORATORY TEST RESULTS (ISAP 2010)

3.1 Introduction

The present section is a synthesis of a detailed analysis published in [5]. Since surface cracking was the main distress observed on the 16 test sections, the proposed cracking index was correlated with the different materials test results. BBR m-value at -15°C and 60s along with TSRST transitional temperature proved to correlate best with the cracking index after 10 years of road service time. Results are not recalled here.

3.2 Cracking amplitude index

The cracking assessment, according to the Swiss standard SN 640 925 [7], defines two parameters that have to be surveyed: the extent and the severity of cracking. The extent of cracking (A) is the relative area of sections where cracking is observed (Table 1).

Table 1: Cracking extent evaluation

Extent value (A)	Description	% of section concerned
0	no cracking	0
1	very localised	< 10%
2	localised to extensive	10..50%
3	very extensive	> 50%

The severity of cracking (S) is 3 for a crack width larger than 10 mm, 2 for a crack width between 2 and 10 mm and 1 for a crack width smaller than 2 mm. The observed cracking is generally smaller than 2 mm. Thus, an intermediate evaluation scale was proposed as shown in Table 2.

Table 2: Intermediate scale for severity evaluation

Severity value (S)	Type of cracking
0.125	Crack initiation
0.25	Small isolated cracks
0.75	Small cracks with some ramifications
1	Small cracks with dense ramification

The “cracking amplitude index” is defined as the combination of the extent and the severity values. The state of cracking after 14 years in operation of the sections placed for comparative testing purposes shows that section 11 does not show any signs of cracking. Its position in relation to the other products appears in figure 3.

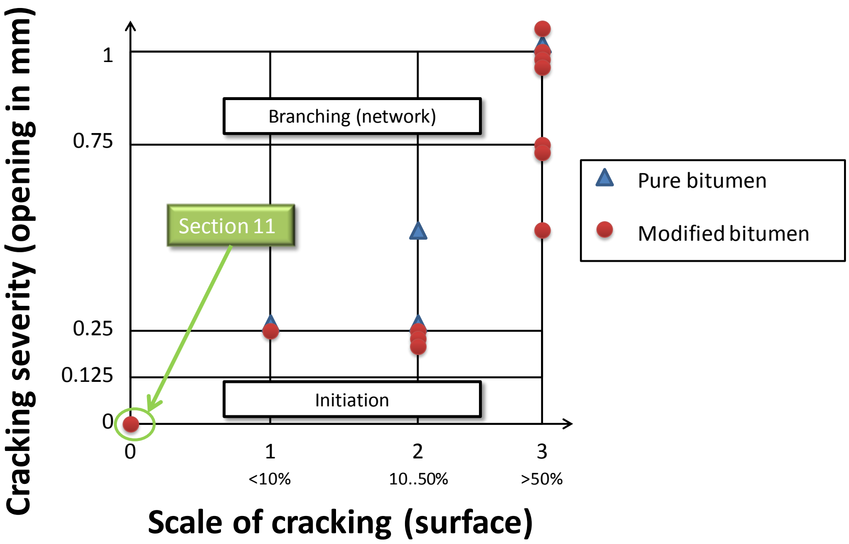


Figure 3: Position of products in terms of their individual state of cracking

Binder performance ranked from the very worse, with an important damage of the wearing course after one year, to the very good with no visible cracking after 14 years of service for the Styrelf 13/80.
Polymer modified bitumen performances showed also the importance of binder processing, and particularly base bitumen and polymer blending. Polymer modified bitumen with crosslinking of the SBS polymer chains is the process that proved its mechanical performance with a satisfactory durability. Styrelf 13/80 belongs to this category of PmBs and is selected for further investigations in parallel with straight bitumen of the same pen grade.

4. EVOLUTION OF STANDARD AND CHEMICAL PROPERTIES OF STYRELF 13/80

Laboratory analysis was carried out on bitumen and mix taken from wearing course samples after 2 years, 8 years and 14 years of service for section N°15 and N°11 and after 19 years of service for section N°11bis. When binders were retrieved, a specific protocol was used to limit changes to binders during the stripping process. The mix was

heated in a microwave oven at a temperature of 80 °C [8]. Binder was then recovered using toluene according to the standard procedure [9]. Binders were characterised using standard bitumen testing, BBR [10] and elastic recovery test [11]. In order to characterise the chemical composition of binders, infra-red spectroscopy (FTIR - Fourier-Transform Infra Red) and Size Exclusion Chromatography (GPC - gel Permeation Chromatography) were used. The first allows chemicals present in the product to be identified, in particular oxidisation levels and monomer content [12]. The second allows visualising molecule size distribution and bitumen ageing [13].
Along with binder tests, low temperature behaviours of the mixes were measured using Thermal Stress Restrained Specimen Test (TSRST) [14] from +20°C at -10°C/h and Uniaxial Tensile Stress Test (UTST) [15] at +20, +5, -10 and -25°C.

4.1 Evolution of the binders during field aging

Figure 4 presents the conventional characterization results for the extracted pure binder and PmB, showing the evolution of penetration and softening point and Fraass breaking point values during service life.

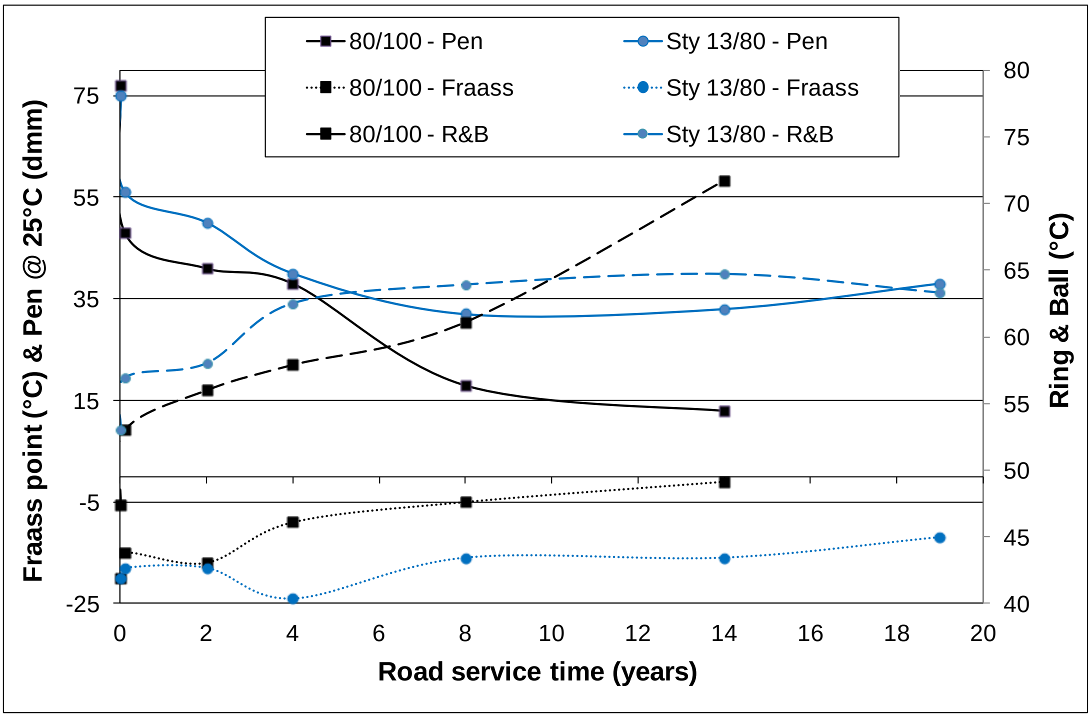


Figure 4: Evolution of penetration, R&B and Fraass during road service time

Both graphs confirm the strong binder aging effect during the mixing, transportation and paving steps. This is evidenced by a strong initial penetration drop (20 to 30 dmm), and a softening point increase (around 8°C). The conventional binder curve demonstrates a continuous rise in softening point and a constant decrease in penetration during road service. Contrarily, the PmB evolution stabilizes after 8 service years, as both penetration and ring and ball plateau. Aging effect seems much lower for the PmB than for the pure asphalt.

The pure binder Fraass brittle point loses about 14 °C during road life after 14 years, whereas the crosslinked PmB lost much less (6°C) during an even longer time period of 19 years.
The same tendency is found for BBR results. The increase in the temperature at which the stiffness is 300 MPa is limited to only 4 °C for the PmB, as opposed to 12 °C for the asphalt.
The limiting m-value temperature evolves more than the iso-stiffness one for the neat asphalt. This result indicates a lower cracking risk for the PmB and higher for the asphalt [16, 17, 18].

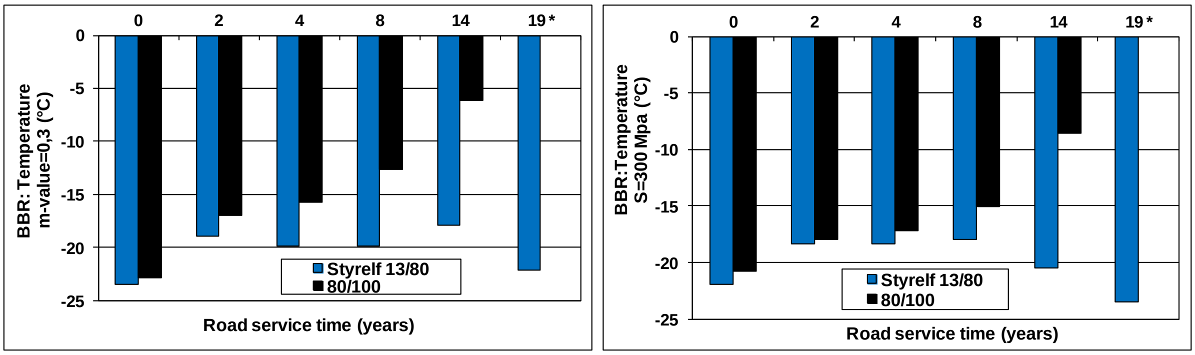


Figure 5: Evolution of limiting iso-stiffness and m-value BBR temperature

In figure 6 the PmB elastic recovery remains at a high level even after 19 service years (only 13 % loss) showing a good and durable relaxation ability at 25°C. Those ER and BBR relaxation characteristics although measured under different testing conditions, particularly regarding temperature are consistent for the PmB.

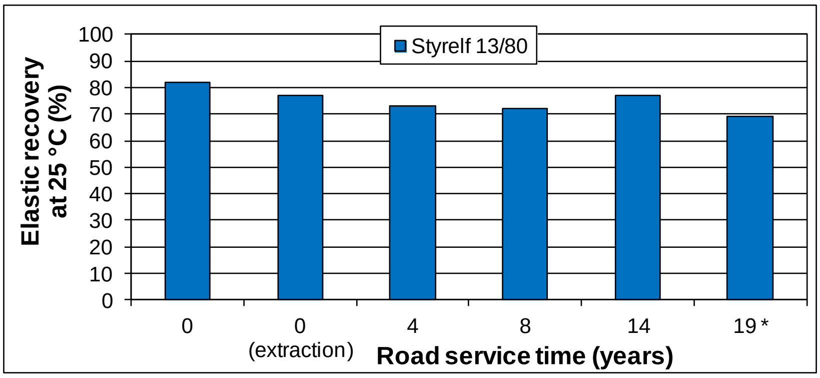


Figure 6: Evolution of elastic recovery during road service time

4.2 Evolution of the low temperature cracking resistance of the mixes

In TSRST, cryogenic stress evaluates the actual stress in a non-trafficked pavement that undergoes rapid cooling. Tensile strength is the maximum stress bearable by the tested layer. Their difference, the tensile strength reserve, measures the maximum traffic stress bearable by the tested layer if it is already undergoing rapid cooling.

Figure 7 shows low temperature measurements for 80/100 and Styrelf 13/80 at different ages. 80/100 reveals lower resistance to low temperature cracking: at every age, it has a higher failure temperature and smaller tensile strength. Moreover, at 14 years, 80/100 cryogenic stress curve is steep, which indicates that the binder gets really hard. Aging has a strong negative impact on the 80/100 mix. However, at the 3 ages, Styrelf 13/80 behaves almost identically with a failure temperature between -26 and -29.5°C. Those behaviours are consistent with BBR measurements and on site performances.

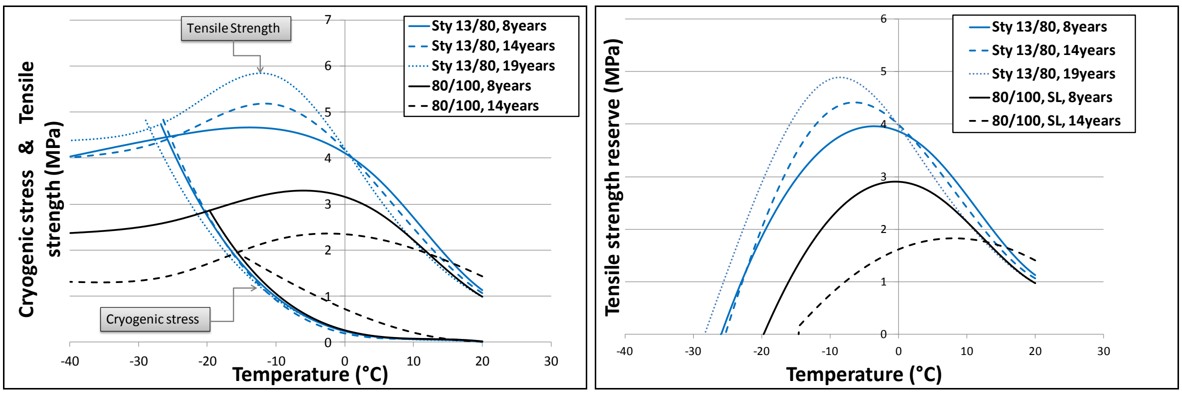


Figure 7: Evolution of cryogenic stress and tensile strength (Left) and Tensile strength reserve for 80/100 and Styrelf 13/80 during road service time.

4.3 Evolution of the chemical composition

Advanced investigations were carried out to link the good performance on site and the good performance recorded in the laboratory with the products' chemical composition. Bitumen ageing is characterised by its hardening which can be explained by the formation of polar groups such as carbonyls or sulfoxides due to oxidisation in the environment. Carbonyl and sulfoxide values are calculated from FTIR spectrums and they express carbonyl and sulfoxide values respectively. They reach a peak after 4 years before decreasing slightly up to 19 years (figure 8). This chemical stability reflects that of performances measured above.

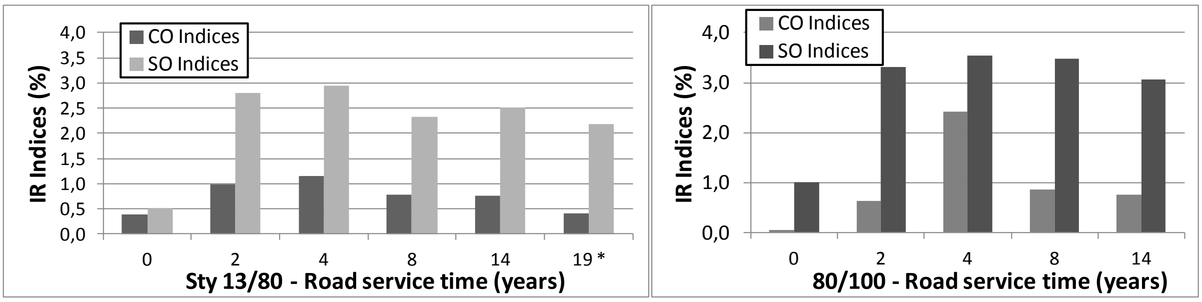


Figure 8: Evolution of polar function contents during road service time.

As well as bitumen, the polymer network undergoes oxidisation in the environment. A previous study [19] proves that the distribution of polymers in this type of product limits oxidisation and that the polymer value is relatively stable. Styrene and butadiene monomer values are determined using transmission values for 700 cm^{-1} and 965 cm^{-1} sections of the infra red spectrum. These show a slight decrease in monomer values during the life span of the Styrelf 13/80 bituminous binder (figure 9). Analysis of GPC spectrums highlights 2 particular facts (figure 10). On the one hand, on the right side of the curve, in compliance with the mechanisms described in [13], low mass bitumen molecules (saturated, aromatic) are incorporated within larger polar molecules (resins and asphaltenes). This confirms the hardening witnessed during penetration and R&B test. On the other hand, on the left side of the curve, polymer evolution can be seen due to the decrease in peaks. Polymers may possibly be partly damaged as a result of chain scission. The signal is however too weak to estimate precisely the extent of the phenomenon.

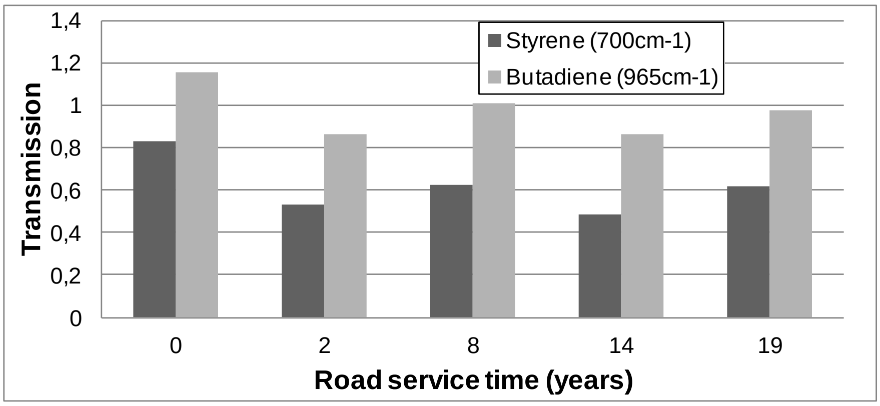


Figure 9: Evolution of polymer content measured by FTIR

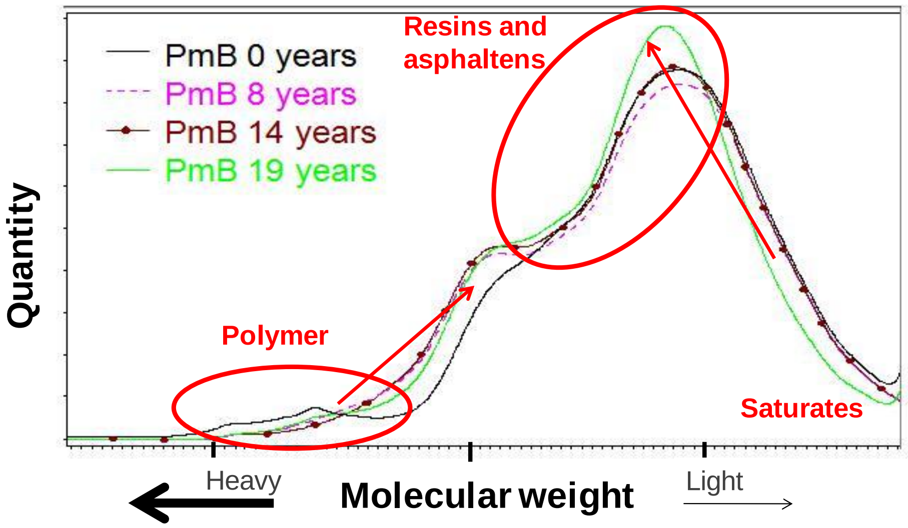


Figure 10: Evolution of molecular mass repartition for Styrelf 13/80 measured by GPC.

5. TRAFFIC AND CLIMATIC EFFECTS ON THE STYRELF 13/80 SECTION

On the 4 km section N°11bis, investigations highlighted the effects of traffic and climate. We can clearly distinguish the right lane or slow lane (SL) where the majority of vehicles drive on to from the emergency lane (EL), which is not subjected to any moving traffic but only climatic effects.
Some samples taken from the 19 year old surface were sawed along their depth: bitumen from the top 15 mm and from the bottom 25 mm were extracted separately for SL and EL. Standard tests were carried out on top, bottom and wholly recovered binder. Values are compared to the initial binder aged under different process: 0 year, 0 year extracted from the road, after RTFOT [20], after 40h in PAV [21] and aged for 19 years in a can in a controlled atmosphere (table 3).
Wholly recovered binders after 19 years provided us with information concerning the specific features of binders. Plasticity range remains high in particular as the Fraass point remains low. Elastic recovery is well above the RTFOT reference value. It was noted that there was a moderate hardening of the binder retrieved from samples taken from the surface subjected to traffic. For all tests carried out, evolution is more pronounced in samples taken from SL than those taken from EL. This more significant ageing rate is also linked to the gritting of motorway lanes which creates a significant thermal shock and when combined with the effect of traffic, contributes to an accelerated ageing process.

Table 3: Styrelf 13/80 properties after 19 years extracted from the whole and at different depth compared to initial binder aged with different process (NB : 'X' = brittle material, '/' = not tested)

Characterization		0 year (initial)	0 year (extracted)	RTFOT	PAV 40h	19 years (can aged)	Slow Lane			Emergency Lane		
							Who.	Top.	Bot.	Who.	Top.	Bot.
Penetration at 25°C	[1/10mm]	75	56	52	27	68	38	24	44	46	26	62
Softening point (R&B)	[°C]	53	56,9	57,9	71	56,4	63,3	68,1	61,2	61,2	67,3	57,8
PI Pfeiffer	[-]	0,6	0,7	0,7	1.5	1,1	1	0,8	0,9	1	0,9	1,1
Fraass breaking point	[°C]	-20	-18	/	/	-15	-12	-10	-16	-18	-12	-17
Plasticity range	[°C]	73	75	/	/	71	75	78	77	79	79	74
Elastic recovery at 25°C	[%]	82	77,3	78	X	80	69,0	X	73,8	76,0	X	82,5

We notice first of all that the average measured value when extracting the entire thickness does not take the heterogeneity of the layer into account. Bitumen from the upper layer for the two tracks is equivalent to PAV 40h for penetration but have a slightly lower softening point. There is no difference with traffic as it is climate which has a greater influence in this area. Bitumen from SL aged more than that from EL. This may be due to pumping of water by traffic or to a physical chemical ageing process induced by repeated pressure. Finally it is worth noting that the binder which was not subjected to the least constraint (EL bottom) shows similar characteristics to bitumen which was stored for 19 years in a can.

The GPC profile on SL reveals the presence of polymer almost intact in the lower layer and its complete disappearance in the top 15mm (figure 11). That observation explains the extended life span of section N°11bis: if in the upper layer (top 15mm) the bitumen underwent advanced ageing, it did however maintain its polymer network in most of the surface layer, keeping its mechanical resistance and cracking properties.

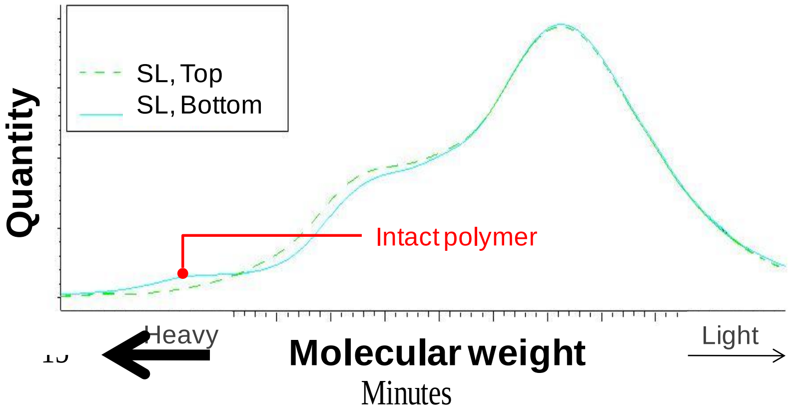


Figure 11: GPC profile of Styrelf 13/80 extracted from the top and bottom of the wearing course.

In order to compare the mechanical performances of surface coatings, fatigue and module tests were carried out using trapezoidal specimens (figure 12 and 13).
For the module, we applied a relative deformation of 40 microdeformations at the following frequencies; 1, 3, 10, 25, and 40 Hz in a range of temperatures, between -10 °C and 30 °C in stages of 5°C [22].
The fatigue test was carried out following standard EN 12697-24 [23] at 10 °C / 25 Hz using 18 samples tested at 3 levels of deformation. We noted that stiffness modules obtained at 15 °C and 10 Hz are 6600 MPa for EL and 7700 MPa for SL. These relatively low values show that the wearing course situated in the middle of the lane undergo moderate ageing. On the other hand, values obtained from the fatigue tests are very high for EL with 172 microdeformations and 150 microdeformations for SL. The EL value indicates that the surface which is not used for travelling and which is considered as the standard reference has suffered little or no damage.

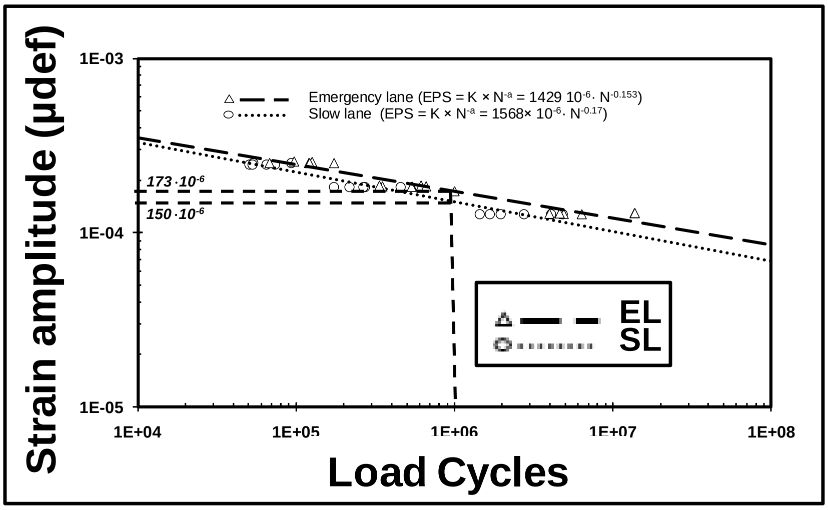


Figure 12: Fatigue curve at 10 °C / 25 Hz - SL (subjected to traffic) and EL after 19 years

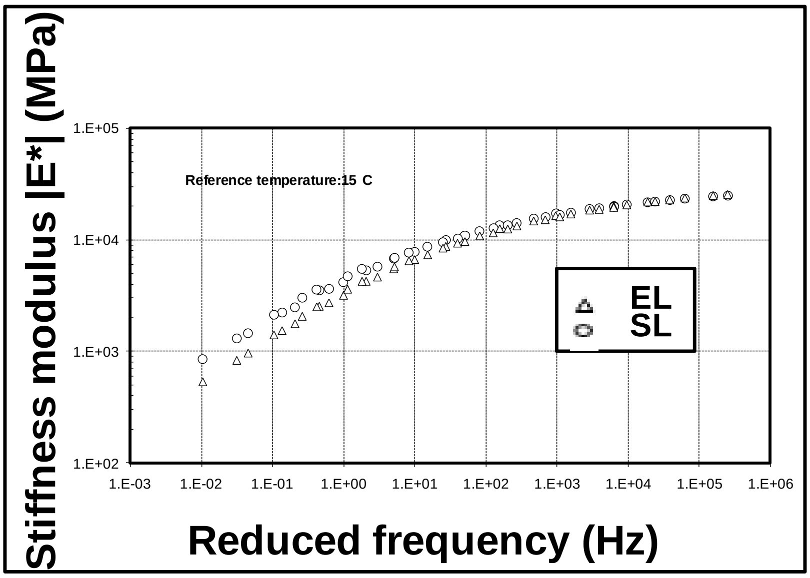


Figure 23: Mastercurve of stiffness modulus - SL (subjected to traffic) and EL after 19 years

6. CONCLUSION

The study conducted on samples from comparative sections subjected to traffic over a period of 2 years, 8 years, 14 years and the complementary section subjected to traffic for 19 years with an average traffic load and relatively harsh weather conditions, showed that:

- The section which contains the Styrelf 13/80 binder has good ageing resistance throughout all the tests carried out. It has extremely good stable properties after 2 years of service. This low evolution of ageing is probably due to the original process of binder reticulation which significantly limits the possibility of oxidisation and improves the durability of the surface.
- Elastic properties of the Styrelf 13/80 binder were maintained at a very high level in relation to initial values which were determined using the basic bitumen. Polymer network evolves during the life of the PmB but is not destroyed. The polymer is still present and active after 19 years.
- Good performance at the lab (binder and mix characterizations) reflected the very good onsite behaviour.
- Differences between slow and emergency lane revealed the impact of traffic.
- The upper layer (top 15mm) is greatly impacted by climate. This top layer is subjected to an accelerated ageing process. The underlying layer ages slightly or almost not at all. The polymer network remains intact and continues to play a strengthening role throughout its 20 years of service.

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