Aging Gradient in a 19 Year-Old Wearing Course in Switzerland

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ABSTRACT: It is generally known that aging of in-place asphalt pavement is not homogeneous. The different sources of damage, such as exposition to weather conditions, tire contact, affect the pavement down to various depths, inducing a gradient of aging in the top layers. The LAVOC at EPFL launched a comparative study about in-place ageing behavior of bitumen in wearing courses in 1988. Test sections were laid down with pure and modified bitumen from a wide range of bitumen producer companies. One of them was made with a cross linked PmB and required no maintenance until 2007. This particular section was further investigated for this study. Reclaimed asphalt was taken from the emergency and right lanes at 2, 8, 14 and 19 years of service and stored. Tests on both mixes and recovered bitumen were performed. The testing of materials collected after 19 years of duty gave some insightful results concerning ageing heterogeneity. An ageing gradient was observed by testing separately bitumen taken from the 15 top millimeters and below. Contribution of weather and traffic aggressions were evaluated thanks to comparison with the initial bulk bitumen stored for 19 years at LAVOC.

KEY WORDS: Aging, oxidation, PmB.

1 BACKGROUND

Modified binders have proven to be smart solutions for road designers and managers during the last three decades. Mainly used in wearing courses, their improved mechanical performances allowed new pavement and mix designs that aim at bearing higher traffic while reducing maintenance periods, which are a major source of costly traffic disturbance. Along with sustainable development, studies have flourished to understand, forecast and/or control pavement evolution during its lifetime. Among these, binder aging and its effect on pavement field performances raise particular interest especially in wearing courses (Voskuilen et al. 2004, Hagos et al. 2009).

Aging is a very complex physical and chemical process. Literature reports both reversible and irreversible mechanisms such as physical, steric and oxidation hardening (Petersen 2009, Hanson et al. 2009). However the main cause of bituminous binder aging in service is commonly known to be oxidation by the oxygen from the air of certain molecules resulting in the formation of highly polar and strongly interacting oxygen containing functional groups (Mill 1996, Petersen 1998).

Two mechanisms allow further oxidation of the entire pavement layer: direct diffusion of oxygen through air voids and/or chemical diffusion of free radicals within the bitumen itself. That phenomenon results in an aging gradient and de facto in a stiffness gradient. Viscosity gradients due to aging have been reported for decades (Coons and Wright 1968, Mirza and Witczak 1994, Farrar et al. 2006) but since it affects only the top 13mm of the pavement, it has been neglected for a long time. During the 1990's, a statistical analysis of former data conducted to the development of the Global Aging System which was a first step towards the modeling of the phenomenon (Mirza and Witczak 1994, Fonseca and Witczak 1995). That model was introduced in various cracking model in the form of multi layered or graded pavement layers (Sangpetman et al. 2004, Dave et al. 2008). Aging gradient was also reported to favors top-down cracking in case of reflective cracks (Nesnas 2006). Lately, binder oxidation and transport models based on basic diffusion laws such as Fick's second law propose a calculation of binder property changes with depth and time (Torrenzio 1998, Prapaitakul 2009).

Yet, if the quantity of data accumulated for pure binder seems sufficient to develop a statistical model, there is no reason for it to fit data issued from mixes with modified binders (Lapalu et al. 2008). Also binder recovery and testing performed on the entire top layer will give an average value for binder properties but a good knowledge of classical aging gradient or a reliable model would help better understanding of surface road pavement behavior.

2 EXPERIMENTAL CAMPAIGN

The results presented here are side-results of a bigger study that intended to evaluate the performance of polymer modified asphalt mixtures compared to pure asphalt ones started in 1988 in the Canton du Valais in Switzerland.

2.1 Background and motivation

At the end of the 1980’s, the Highway Department of the Canton of Valais and the Laboratory for Traffic Facilities at the Swiss Federal Institute of Technology participated in the preparation of Swiss recommendations concerning polymer modified binders. However, limited information based on experience was available at that time despite the use of such products for many years. In 1988, the National Roadway Service of the Canton of Valais constructed the superstructure and the pavement of the N9 motorway over a distance of 15km. One stretch was made available for the execution of test sections in order to compare the behaviour of polymer and additive modified bituminous mixtures with that of pure bituminous mixtures. A large observation field with identical conditions was made available for the construction of 16 different test sections, each 300 m long. Twelve modified and four pure asphalt cements, used as references, were selected for the construction of the wearing courses (Dumont et al. 1989, 1993, 2002, 2004). The pavement was designed according to the Swiss standard SN 640322 of 1971 for a lifetime of 20 years, 1600 daily ESAL of more than 8 tons and a 5% annual traffic progression.

These wearing courses in asphalt concrete AB 16S were built in 1988 under the same construction site conditions including same aggregates, filler, mixing plant, finisher, rollers and weather conditions and kept under traffic until 2002 with no maintenance. Two binders produced by Elf now Total were involved (pure bitumen 80/100 and a Styrelf® 13/80). A complementary section laid in 1988 in continuation of the test sections and kept under traffic until 2007 with the product Styrelf® 13/80, similarly industrially produced as binder P11 earlier mentioned.

For all sections, service and climate conditions were identical for 14 years in use. Then the comparative test sections were replaced due to the cracking failure of some of them, but the complementary crosslinked PmB section remained in use for another 5 year period - it still is as of summer 2009.

Considering the extremely good aging resistance of the wearing courses containing Styrelf 13/80, a focus on the follow up survey of the two sections presented above needed to be done. In order to assess the long-term evolution of the test sections behaviour, many monitoring surveys and laboratory tests were carried out during the lifetime of the pavement, especially on the wearing course. Laboratory tests included conventional (Figure 1) and "advanced" test procedures on binders and mixtures. Different assessment ages for in-place mixtures were chosen (0, 2, 4, 8, 14 and 19 years) and a study to determine what binder or mixture properties predict best long-term performance was conducted (Dressen et al. 2010).

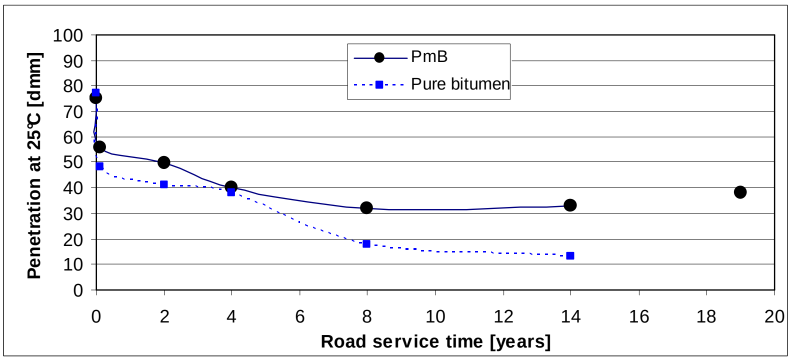
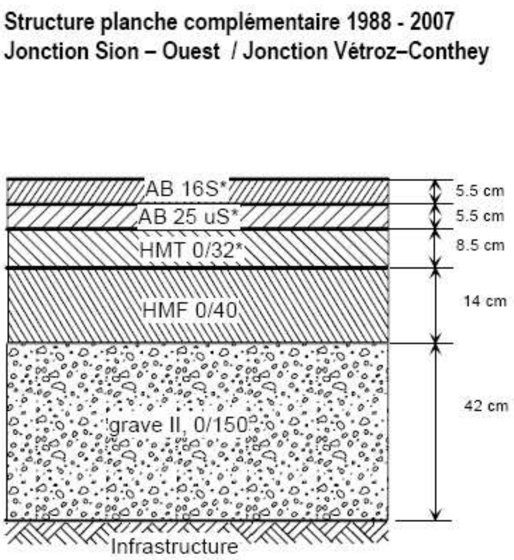


Figure 1: Evolution of the penetration of pure and polymer modified bitumens along the 19 years of service life.

During the process of binder recovery and testing, the issue of aging gradient was raised. The binder recovery was performed for the whole pavement thickness. Therefore there was a concern about how much the binder in the very top layer ages compare to deeper binder and to what extend the average properties reflect the reality.

2.2 Mixes and binder presentation

Figure 2 shows the pavement design of the complementary section from which the material considered in that paper were extracted. 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

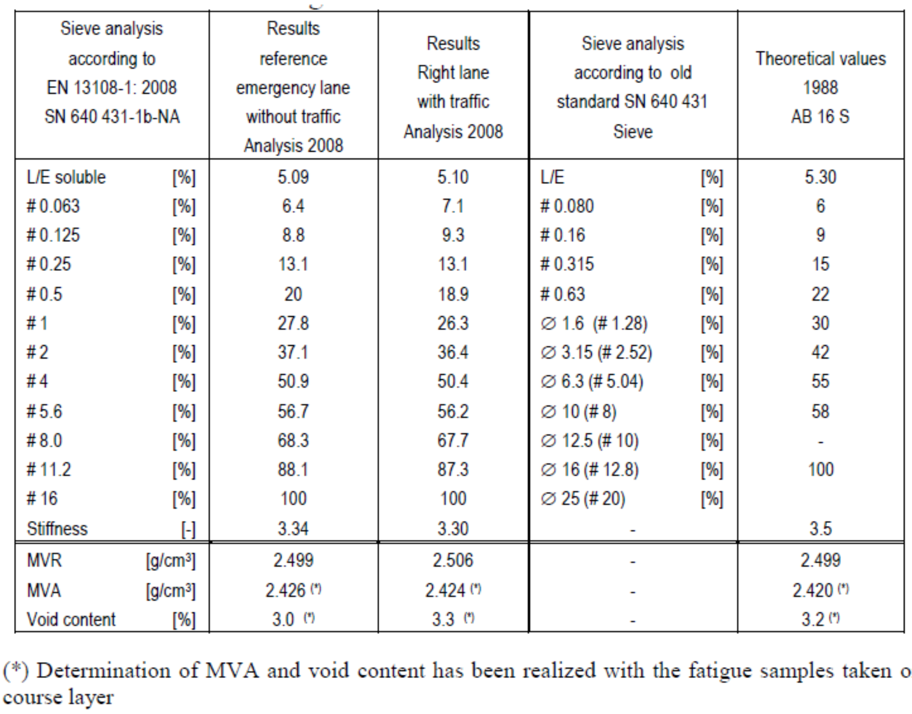


* Sieve diameters ∅ according to old standard SN 640 431 (1976)

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

Recovery and gradation tests were also performed. They are reported in Table 1. Both wearing courses featured 5.6 percent binder by weight of aggregates. They have similar low air void content of 3 and 3.3%.

Table 1: Gradation curve, binder and void content of the emergency and right lanes compared to the 1988 design values.



Sieve analysis according to EN 13108-1: 2008 SN 640 431-1b-NA		Results reference emergency lane without traffic Analysis 2008	Results Right lane with traffic Analysis 2008	Sieve analysis according to old standard SN 640 431 Sieve		Theoretical values 1988 AB 16 S
L/E soluble	[%]	5.09	5.10	L/E	[%]	5.30
# 0.063	[%]	6.4	7.1	# 0.080	[%]	6
# 0.125	[%]	8.8	9.3	# 0.16	[%]	9
# 0.25	[%]	13.1	13.1	# 0.315	[%]	15
# 0.5	[%]	20	18.9	# 0.63	[%]	22
# 1	[%]	27.8	26.3	∅ 1.6 (# 1.28)	[%]	30
# 2	[%]	37.1	36.4	∅ 3.15 (# 2.52)	[%]	42
# 4	[%]	50.9	50.4	∅ 6.3 (# 5.04)	[%]	55
# 5.6	[%]	56.7	56.2	∅ 10 (# 8)	[%]	58
# 8.0	[%]	68.3	67.7	∅ 12.5 (# 10)	[%]	-
# 11.2	[%]	88.1	87.3	∅ 16 (# 12.8)	[%]	100
# 16	[%]	100	100	∅ 25 (# 20)	[%]	
Stiffness	[-]	3.34	3.30	-		3.5
MVR	[g/cm³]	2.499	2.506	-		2.499
MVA	[g/cm³]	2.426 (*)	2.424 (*)	-		2.420 (*)
Void content	[%]	3.0 (*)	3.3 (*)	-		3.2 (*)

(*) Determination of MVA and void content has been realized with the fatigue samples taken on the center of the wearing course layer

In order to address for the aging gradient, it was decided to extract separately the binder from the top 15 millimeters and the rest of slabs. The top 15mm of 19 year-old slabs taken from both the right and emergency lane were cut off with a saw and the corresponding binder is referred as ‘top’ binder. The binder extracted from the 40mm left is referred as ‘bottom’ binder. It was unfortunately impossible to measure properties at more than 2 depths because the low thickness of the layer made further sawing impossible. However it should not be a problem since the binder properties are said to be homogeneous below the top 13mm of the pavement (Coons and Wright 1968).

Complementary to regular data on the original binder (fresh binder, RTFOT and PAV aged) that were included in the former study, a binder stored for 19 years in a sealed can at 20°C was tested. That product is supposed to simulate the aging of binder that is not exposed to oxidation.

2.3 Characterization methods

Asphalt aging was performed by means of laboratory tests, the rolling thin film oven test (RTFOT) according to EN 12607-1 and the pressure aging vessel (PAV) according to EN 14769.According to Superpave, RTFOT simulates the short term aging of asphalt resulting from mixing, transportation and paving whereas RTFOT + PAV simulates long term aging in the field for a 5 to 10 year service period. Although this aging procedure was developed for conventional binders, only little information is available for modified ones. The binders were taken at the mixing plant and then subjected to accelerated aging in the laboratory.

The field binder samples were first extracted and recovered. This important step was carried out according to the Swiss standard SN 670 403a and EN 12697-3:2005 at LAVOC. This laboratory had built up a huge experience on extraction and recovery of conventional and modified binders (Pittet et al. 2002).

The pavement cores obtained by sawing the layers were heated in the microwave and then divided into 3500g portions. The cores were then extracted by toluene with double centrifugation to separate the binder from the aggregates according to SN 670 401a and EN 12697-3:2005. It is based on recovery of a mass of residual asphalt between 120 and 150g. In the first evaporation phase run in a rotating evaporator, boiling toluene is evaporated maintaining the bath at a 145 ± 1°C temperature under a 40 to 50kPa pressure and a 65 ± 5rpm rotation speed. The residual solvent evaporation proceeds lowering the pressure down to 1.9 ± 0.1kPa. These conditions are maintained for 20 min ± 30 seconds.

After complete solvent removal, different binder properties were determined for both top and bottom layers. Consistency parameters such as the penetration at 25°C (EN 1426) and the ring and ball softening point (EN 1427). Elastic recovery according to EN 13398 characterizes the binders' ability at ambient temperature to return to its original shape after deformation.

Gel permeation chromatography (GPC), eluting molecules as a function of their size, was employed to determine the molecular weight distribution. Thus, a 100µl binder sample, 0.5% diluted in THF, was injected in a Waters® Styragel column (HR4 + HR2 + HR0.5) running at 40°C under 5068 kN/m² pressure. The molecules passing though the column were detected by a refractive index detector as a function of time. The printout chromatogram represents the binder molecular weight distribution (Brulé et al. 1983, Ishai 1996). Earlier works (Molenaar et al. 2004) found GPC powerful to study the effects of asphalt modification and aging.

3 RESULTS

3.1 Mechanical gradient

The results of the penetration, softening point and elastic recovery tests are gathered in Figures 3 to 5. The values measured on averaged binders are compared with top and bottom extraction for both Right Lane (RL) and Emergency Lane (EL). The original, short-term aged (RTFOT) and long term aged (PAV) values are also recorded. Finally, the can aged values are supposed to evaluate binder aging without air exposure.

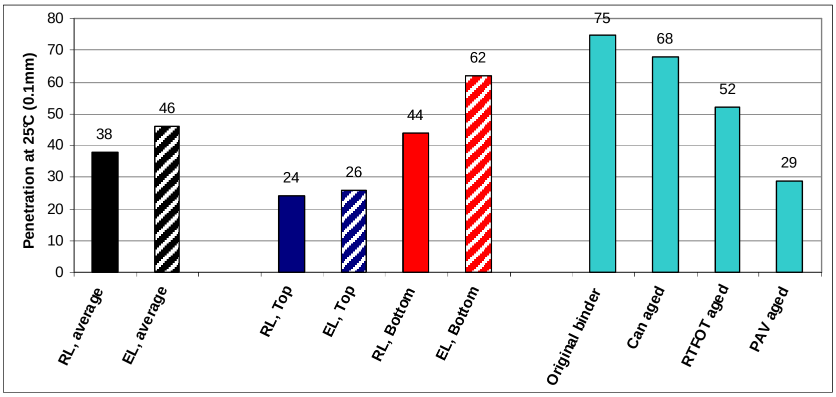


Figure 3: Penetration at 25°C of top and bottom binders compared to average and laboratory aged binders.

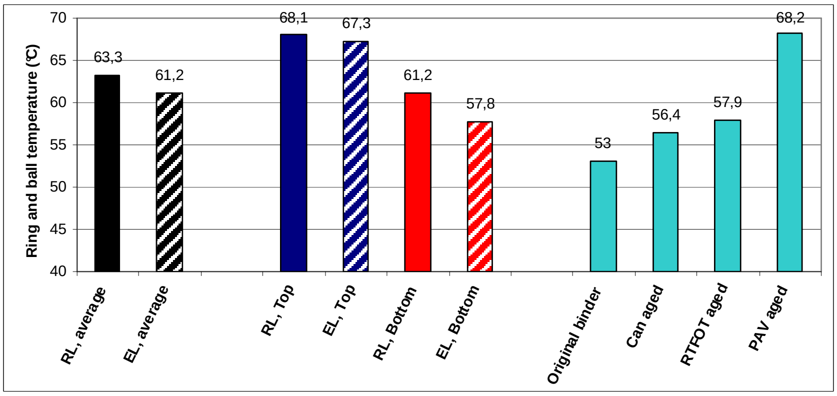


Figure 4: Softening temperature of top and bottom binders compared to average and laboratory aged binders.

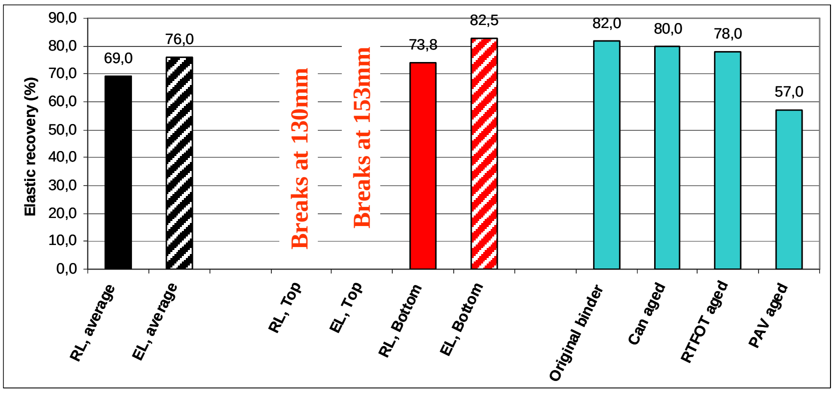


Figure 5: Elastic recovery of top and bottom binders compared to average and laboratory aged binders. Elastic Recovery could not be conducted on RL and EL, Top because the specimens broke before reaching maximum elongation.

A big discrepancy is found between top and bottom binder for both RL and EL. There is a

20dmm and 6.9°C difference for penetration and softening point in RL. The gradient is even higher for EL with a 37dmm and 10.3°C difference. For the penetration and softening point, the averaged binders give intermediate values which could be determined by simple mixing law.

Top RL and EL binders have very similar features which match those of PAV aged binder for penetration and softening point. However, they are much more brittle and break respectively at 130 and 153mm elongation. The polymer modifier in the top layer is starting to become less efficient after 19 years on the road whereas it still has some effect after PAV aging. PAV can be used to forecast penetration and softening point but is not able to estimate the degree of polymer degradation after 19 years.

Deeper, aging does not have the same impact with and without trafficking. Looking at penetration, softening point and elastic recovery, the RL bottom binder is a little bit more aged than RTFOT binder whereas EL bottom binder is less aged than RTFOT binder (with an even better Elastic Recovery than the original binder).

3.2 Chemical gradient

Figure 6 illustrates the chemical average evolution of the binder through GPC distribution curves. The chromatograms show a shift towards higher molecular weights with aging for the peaks corresponding to resins and asphaltenes. On the other hand, the 2 smaller peaks located in the highest molecular weights reveal the polymer presence. They seem to flatten and migrate towards lower molecular weight with aging.

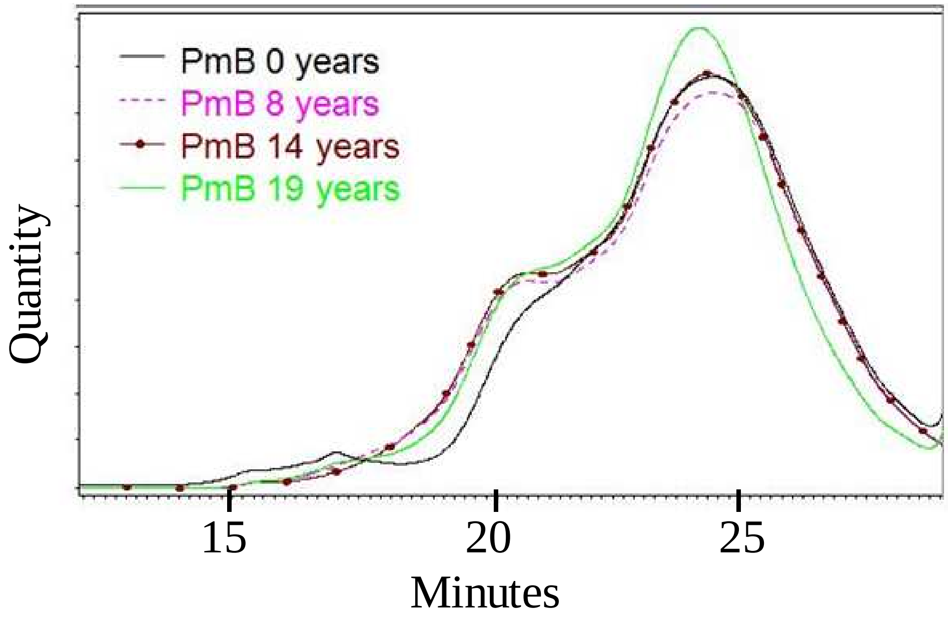


Figure 6: GPC distribution curve for averaged binders at 0, 8, 14 and 19 years (Dreessen et al., 2010).

GPC chromatograms were also performed on binders extracted from 19 year-old EL and RL (Figure 7). Both GPC distributions reveal the degradation of the polymer matrix in the top layer, which is consistent with elastic recovery results. The shift towards lower molecular weights implies that polymer does not disappear but breaks into smaller molecules. On the other hand, the polymer still shows up in the bottom layer, which is also consistent with the mechanical properties.

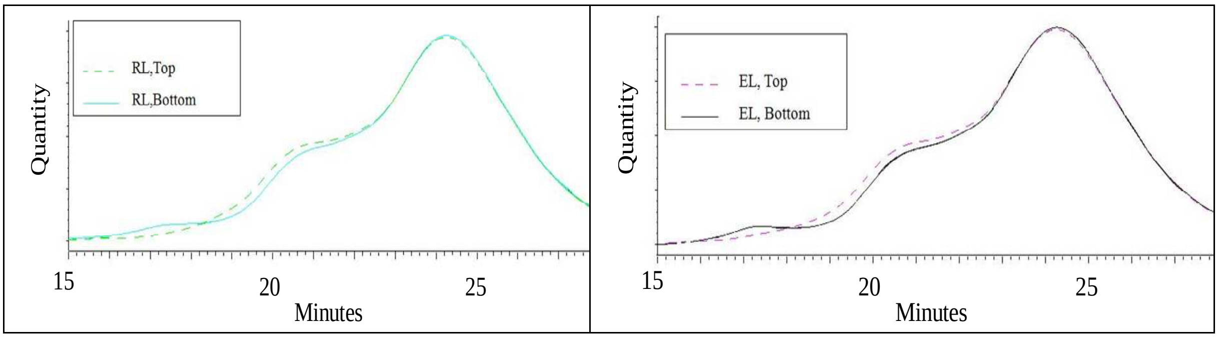


Figure 7: GPC distribution for binders extracted from RL (left) and EL (right).

4 CONCLUSIONS

The aging gradient was observed in a 19 year-old wearing course built with a crosslinked polymer modified binder in order to:

- Verify to what extend values measured from the whole thickness are pertinent.
- Assess for the exceptional resistance against top-down cracking of that particular pavement section.

A mechanical property gradient was similarly observed for both lanes with bigger differences for bottom than top binder. The following conclusions can be drawn:

- Binder extracted from the whole thickness of a thin wearing course gets the average properties of the inhomogeneous binder in its whole. If one can model the aging gradient from lab experiments (with GAS for instance), the knowledge of the averaged properties is sufficient.
- The top 15mm aging is mainly driven by oxidation regardless of traffic. It is more aged than after PAV because polymer degradation (presumably by chain scissions as seen by GPC) is more advanced.
- Deeper, the binder is protected from oxidation and the influence of trafficking is much more obvious: binder ages faster in a trafficked pavement. Without any traffic, the deeper binder ages almost as kept in a sealed can. This result explains the delay in top down cracking with this particular PmB, able to conserve high cohesion even after 19 years.

Unfortunately, due to the lack of point measured, a depth profile extrapolated - from the GAS model for instance - could not be computed. Therefore further calculation with computational model to evaluate the gain in resistance against top-down cracking would be hazardous. Also we do not have the time evolution of that profile. However, the measures on averaged binders tend to show that the road studied did not evolve after 8 years and so did the aging gradient.

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