- Final Paper –

LONG TERM EVOLUTION OF SBS CROSSLINKED POLYMER MODIFIED BINDER IN COMPARISON WITH CONVENTIONNAL BITUMEN: FIELD STUDY

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Paper abstract: (max 300 words)

In order to study the long term evolution of bituminous binders, especially polymer modified binders in comparison to conventional asphalts, sixteen comparative test sections were constructed in Switzerland on the RN9 motorway in the Canton of Valais in 1988. To be able to compare conventional, neat asphalt with polymer modified binder (PmB's), it was decided to lay down under the same construction site, traffic and climatic conditions these test section of bituminous concrete. For these sections, only the wearing course binders varied. More analysis after 19 years was performed on a complementary road section constructed with a similar PmB binder in 1988.

Referring to all these test sections, this article deals with the comparison of straight run asphalt and a crosslinked polymer modified binder obtained to a proprietary process, under field aging conditions.

Results (TSRST, UTST, BBR, recovered binder characterization) at the initial state and after up to 14 years of age were obtained for both binders. Additional data after 19 years is available for the PmB. The various bitumen and asphalt mix results are correlated with observed sections surface distresses.

The paper highlights the very good performances in term of durability of the crosslinked polymer modified binder in comparison to the conventional binder.

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1. Background

1.1 The 1988 LAVOC study for PmB performance assessment

Modified binders started being used extensively about thirty years ago with the aim of improving the mechanical performance of bituminous pavements, particularly on the surface course. This development came in response to traffic increase, to reduce maintenance periods, which are a major source of costly traffic disturbance.
In this new era of sustainable development where materials enabling durability enhancement are being asked for, the knowledge of field aging mechanisms should be of particular interest [1, 2].

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 15 km. 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 [3, 4, 5, 6]. 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.

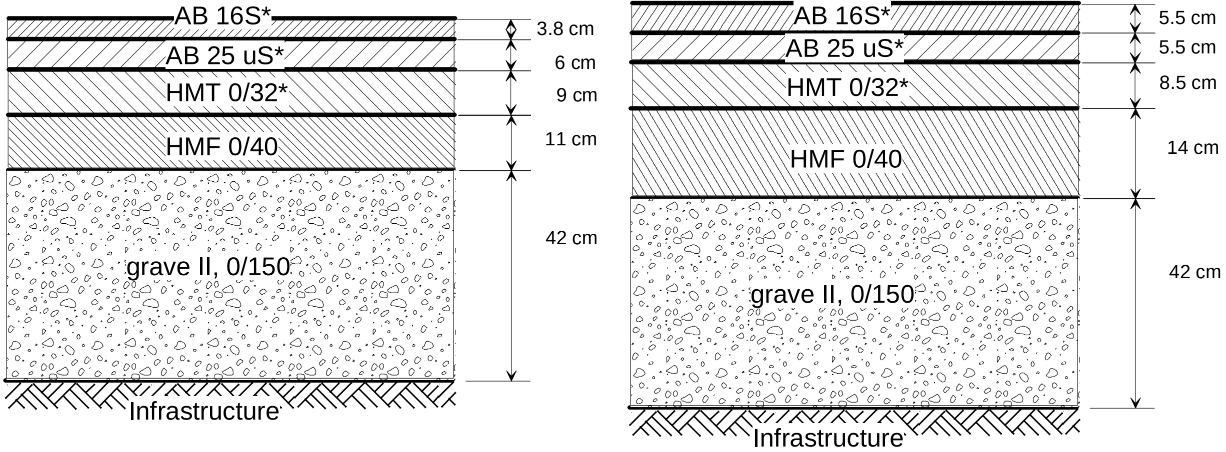
1.1.1 TOTAL binder section N°15 (80/100), N°11 and N°11bis (Styrelf 13/80)

The comparative test sections included a reference pure asphalt 80/100 (N°15) and an in situ crosslinked styrene-butadiene copolymer modified asphalt Styrelf 13/80 (N°11), with 3% polymer loading, industrially produced according to a proprietary process. Both unmodified and modified binders were made out of the same crude oil bases.
Both sections have the same structure geometry and aggregate materials except the binder used in the wearing course [4]. The wearing course thickness was measured at 38 mm.
A complementary section (N°11bis) 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 N°11 earlier mentioned. It was constructed with a slight difference in thickness of the

AB 16 S wearing course which was 55 mm as demonstrated in figure 1. Both wearing courses featured 5.6 percent binder by weight of aggregates.

Comparative test section structure
1988 - 2002
Lot 342 between Jonction Vétroz–Conthey and Ardon (Switzerland)
Section 11 Section 15
Styrelf® 13/80 B 80/100

Complementary test section structure
1988 - 2007
Junction Sion – Ouest / Junction Vétroz–Conthey (Switzerland)
Section11bis
Styrelf® 13/80



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

FIGURE 1 Structure and foundation of the highway (test and complementary section)

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.

1.1.2 Traffic and site situation

The considered road section on the A9 motorway supports mainly touristic traffic. Heavy goods vehicles (HGV) on this section serve essentially the local industrial area, thus the heavy traffic aggressiveness is rather moderate.

Traffic monitoring on this section shows an annual growth rate of about 2.91% and an average annual daily traffic of 23’605 vehicles during the period from 1988 to 2007. HGV represent 6% of the total traffic. This traffic level corresponds to 830 Equivalent Standard Axle Load of 80 kN (Swiss traffic class T4).

1.1.3 Climate

Site climate data were collected thanks to a dedicated weather station situated beside the section. The weather instruments include temperature sensors placed in the body of the pavement at different depths, a hygrometric sensor, and a radiometer allowing measurement of solar visible and infrared radiations. Data were recorded from 1992 to 2007 and permitted calculation of pertinent statistical values which characterize site climatic conditions.

The considered region shows climatic conditions typical of the Valais region (Alpine valleys), particularly:

- Many sunny days: 270 day per year

- Periods of extreme cold
- Days with extremely fast cooling rates

Daily maximal temperatures are regularly over 30 °C which is quite exceptional in Switzerland. Daily minimal values are often under -5 °C for long periods during the cold season. Winters 1998/1999 and 2005/2006 showed even long periods with a temperature of the air lower than -10 °C.

The important number of periods combining cold temperatures with uncovered sky induces frequent appearance of high cooling rates inside the wearing course of the pavement. Figure 2 shows the occurrence of days corresponding to different levels of daily maximal cooling rates in the air and in the pavement during the 15 years of data collection. It was noted that for 20 days, this cooling rate exceeded 5 °C/h in the air, which is considerable. For comparison, the Thermal Stress Restrained Specimen Test (TSRST) recommends a cooling rate of 10 °C/h [7].

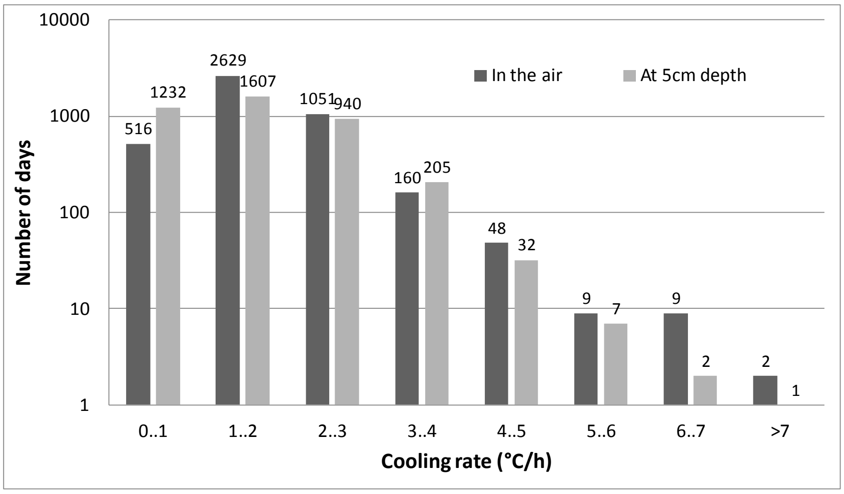


FIGURE 2 Occurrence of maximal daily air and pavement cooling rates at 5 cm depth (period from 1992 to 2007).

1.2 Surface damage observed after 14 years

The surface damage noted on the test sections falls into three categories: aggregate polishing (loss of surface friction), loss of materials and cracking.

Aggregate polishing (loss of surface friction) was noted on all sections with a similar amount of damage. This is essentially linked to the features of aggregates which have the same petroleum base. The loss of materials as a result of surface aggregate stripping is less serious and can be found spread out over the 16 sections.

Cracking proved to be the determining factor in this study. It is taken into account with a high bearing capacity in assessments carried out in Switzerland.

The Swiss standard SN 640 925 [8] assesses parameters in order to determine the state of cracking or Extent A (table 1) and S gravity (severity) (table 2).

Range/Extent (A)	Description	% of the surface concerned
0	No cracking	0
1	Concentrated in a specific area	< 10%
2	Extensive cracking	10 - 50%
3	Very extensive	> 50%

TABLE 1 Range assessment

The magnitude of the cracking problem is set at a value of 3 for cracks exceeding 10 mm, 2 for cracks measuring between 2 and 10 mm and 1 if the crack is smaller than 2 mm. As the cracks observed were all under 2 mm, a lower rate of damage gravity was applied to table 2.

Severity (S)	Type of crack
0.125	Crack initiation
0.25	Small isolated cracks
0.75	Small cracks with some branching
1	Small cracks with significant branching

TABLE 2 Intermediate scale of cracking

The cracking index is defined as a combination in percentage of the scale and severity (S).

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.

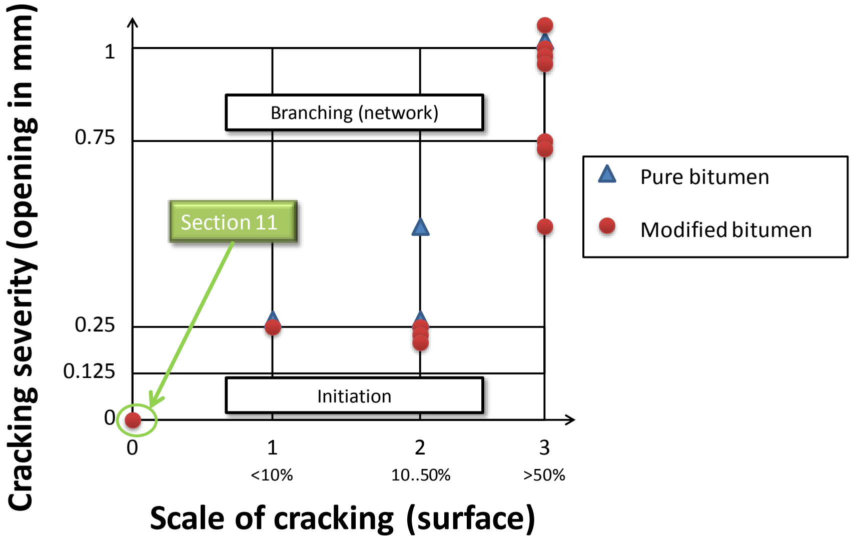


FIGURE 3 Position of products in terms of their individual state of cracking

2. Experimental campaign

The main goal of the study was the evaluation of the long term performance of polymer modified asphalt mixtures compared to pure asphalt ones, focusing on the follow up survey

of the sections presented above (N° 15, 11 and 11bis), the binders of which were supplied by the company Elf now Total. The other sections were only considered as literature references. For both technical (different timeframe) and confidentiality reasons, the authors could not use them.
Then, this study aimed at the selection of binder or mixture properties to predict long-term performance by carrying out conventional and new testing procedures. 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.
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.

Laboratory tests included conventional 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).

2.1 Characterization methods

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 [9] at LAVOC. This laboratory had built up a huge experience on extraction and recovery of conventional and modified binders [10].

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 [11]. 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 ± 0.1 kPa. These conditions are maintained for 20 min ± 30 seconds.

After complete solvent removal, different binder properties were determined. Consistency parameters such as the penetration at 25°C (EN 1426), the ring and ball softening point (EN 1427) as well as the dynamic viscosity at 130°C were measured.
Elastic recovery according to EN 13398 characterizes the binders’ ability at ambient temperature to return to its original shape after deformation.
FTIR analysis was conducted to see the evolution of polymer content.

Low temperature properties of the binders were assessed using the Fraass breaking point and the Bending Beam Rheometer (BBR) (EN 14771). BBR is used for the characterization of performance at low temperature by three-point-bending. Two critical temperatures below which there is a risk of cracking are calculated. The first one is the temperature at which the stiffness modulus S (60 s) is 300 MPa and the second one is the critical temperature at which the m-value, slope of the stiffness modulus as a function of loading time, has a value of 0.3 at 60 seconds loading time. The m-value is related to the binder relaxation-capability.

Along with binder tests, low temperature behaviours of the mixes were measured using Thermal Stress Restrained Specimen Test (TSRST) (AASHTO TP 10) [12] and Uniaxial Tensile Stress Test (UTST). Tests were performed on 35(±2)x50x160mm specimens cut in slabs taken from the wearing course. During TSRST, the specimen is kept at constant length while temperature decreases from +20°C at -10°C/h. Cryogenic stress is recorded as a function of temperature. UTST was performed at +20, +5, -10 and -15°C. Tensile strength as a function of temperature was obtained by interpolation with a cubic spline function.

2.2 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.

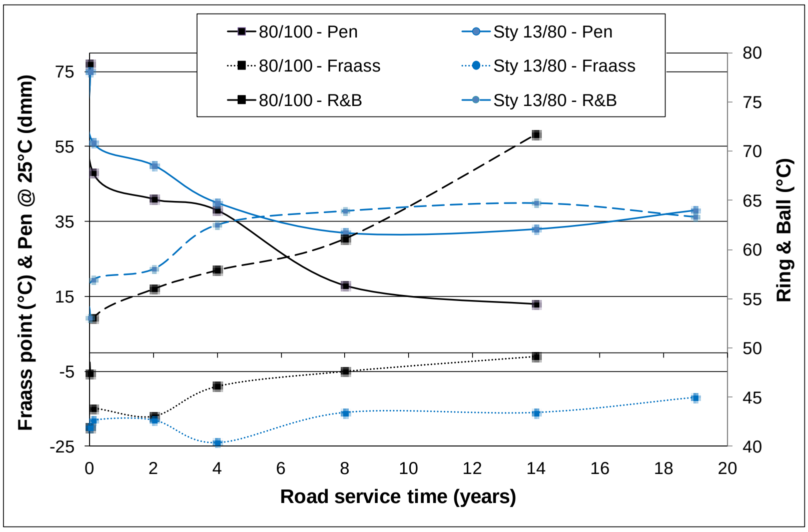


FIGURE 4 Evolution of penetration, R&B and Fraass during road service time

All curves 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.
This latter material is marked 19* in figure 5.
The same tendency is found for BBR results (figure 5). 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 [13, 14, 15].

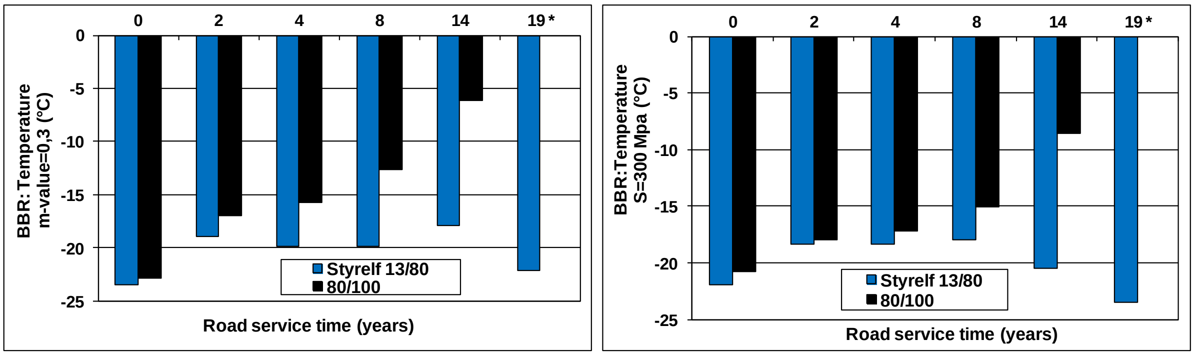


FIGURE 5 Evolution of limiting iso-stiffness and m-value BBR temperature

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.

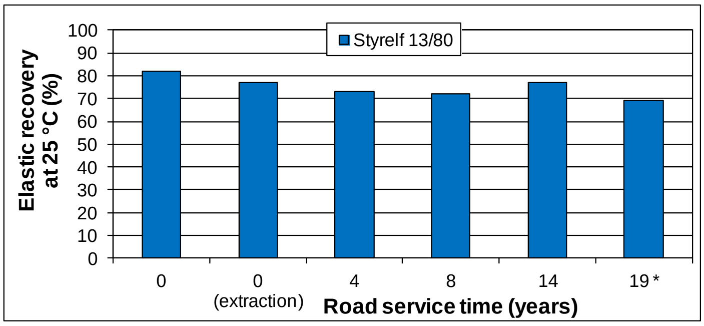


FIGURE 6 Evolution of elastic recovery during road service time

For the crosslinked PmB, the eventual polymer degradation was followed by measuring the characteristic IR bands at 700 and 965 cm-1 for respectively the styrene and butadiene polymer units (figure 7). As already mentioned, the most important degradation occurs during the first two years including the asphalt mix production. But overall the polymer content is fairly stable, as earlier studied [16] and considering that extracted binders were analyzed - this implies possible exclusion of insoluble aged polymer molecules.

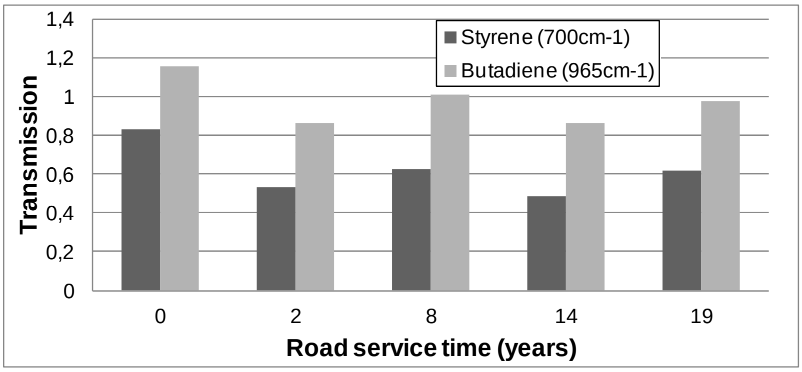


FIGURE 7 Evolution of polymer content measured by FTIR

2.3 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 8 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.

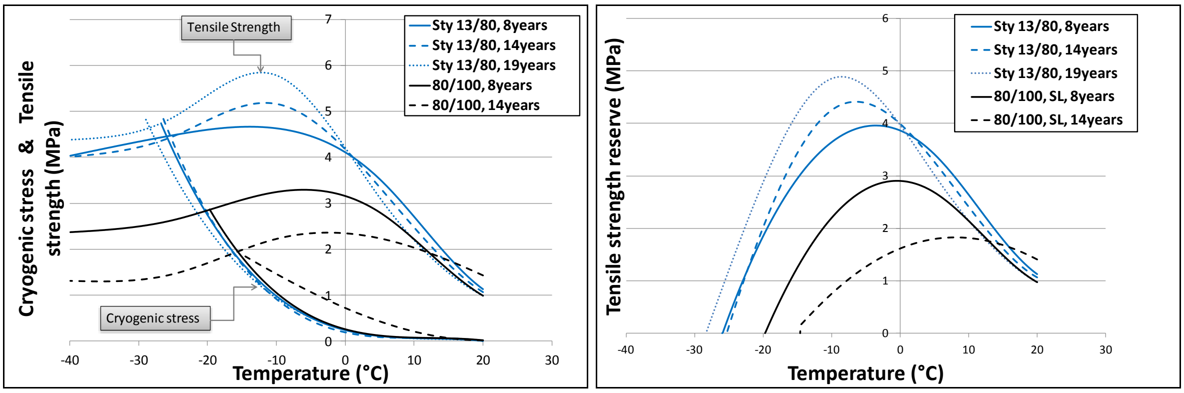


FIGURE 8 Evolution of cryogenic stress and tensile strength (Left) and Tensile strength reserve for 80/100 and Styrelf 13/80 during road service time.

3. Conclusions

This paper focused on the field aging properties of a conventional binder in comparison to a crosslinked polymer modified binder to study a material expected to enhance the pavement wearing course durability.

The study covered a long road service time until 19 years for the PmB and 14 years for the conventional binder.

Based on the findings of this study, the following conclusions can be drawn:

- Field aging affected the plain asphalt much more than the polymer modified binder. This was confirmed by all standardized binder characterizations.
- Within the characterizations performed inhere, BBR criteria represent good indicators for the PmB performance in terms of thermal cracking and aging resistance. It is consistent with both lab and on-field low temperature cracking resistance
- The crosslinked polymer network remains present (FTIR) and active (elastic recovery) for 19 years. This lower aging sensibility was explained elsewhere by a very homogenous polymer repartition in the binder matrix for this binder type [16].
- Globally the long term behaviour of the PmB used in this study presents a high and outstanding performance level. The decrease in mechanical properties remains

relatively low and stable after eight years up to fourteen and even nineteen years. The weathering stability of the PmB compared to conventional asphalt is in the present case, very encouraging.

Obviously, these conclusions are limited within the framework of this study. Other PmB's' or straight asphalts would behave differently in the long term on the road.
More work is planned to address the relationships between these binder properties and the section cracking performances as a function of time and location in the pavement design.

Acknowledgement

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