Combined traffic and climate effects on durability of pavement mixture with polymer modified binder

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ABSTRACT: Pavement distress evolution is strongly related to the combined effects of traffic and climate. Test sections on the A9 motorway in Switzerland were monitored during 19 years and allowed the distinction and the evaluation of these effects.
The assessment method focused on surface pavement condition and analysis of the wearing course material. The investigation is carried out on the slow lane with combined traffic and climate effects, as well as on the emergency lane which supported only the climate effect. The traffic on the test section is moderate; however, the climatic conditions are harsh including particular low and high temperature with strong daily variations.
Besides long term behavior which is different depending on the binder type, significant discrepancies are observed through a wide range of laboratory tests (TSRST, BBR, modulus, fatigue, recovered binder characterization). The test results are correlated with observed sections surface distresses.
Rankings of pure and modified binders, which were conducted after 10 years of service, are confirmed and refined thanks to recent laboratory tests and section monitoring carried out after 14 and 19 years of service. Thus, traffic and climate effects are separated and their relative weights on pavement surface distress are determined. On the other hand, specific performances of different modified binders are confirmed within this research.

KEY WORDS: Aging, long-term performance, polymer modified binder

1 PREAMBLE AND HISTORICAL BACKGROUND

In 1988, the National Roadway Service of the Canton of Valais constructed the superstructure and the pavement of the A9 motorway over a distance of 15 km. One stretch was made available for the execution of test sections in order to compare the behavior 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, 300 m long each. All sections have the same pavement structure and materials except the wearing course binder. A detailed description of the work conducted for the monitoring of these test sections is given in (Dumont and Ould-Henia, 2004). A particular attention is put in this paper on the sections number 11 and 15 produced respectively with Styrelf® 13/80 polymer modifier bitumen and a classical pure bitumen (80/100 penetration grade).

Beside the previous sections, an additional section of 4 km long was built with the Styrelf® 13/80 binder. This pavement is still in service at the present time.

2 SITE SITUATION AND TRAFFIC AND CLIMATE CONDITIONS

2.1 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).

2.2 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 days 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.

In what follows, solar radiation considered in this paper is the net radiation which is the measure of incoming minus upwelling radiation over the pavement surface. Negative and positive net radiation values induce respectively cooling and heating of the road surface.

Average annual net radiation is approximately 130 W/m^2. Daily average can reach 200 W/m^2 during summer and -20 W/m^2 in winter. The latter negative value induces a global cooling of the road surface through pavement body radiation during many days. Maximal daily net radiation is often over 700 W/m^2 in summer.

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 1 shows the occurrence of days corresponding to different levels of daily maximal cooling rates 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 (Pucci 2000).

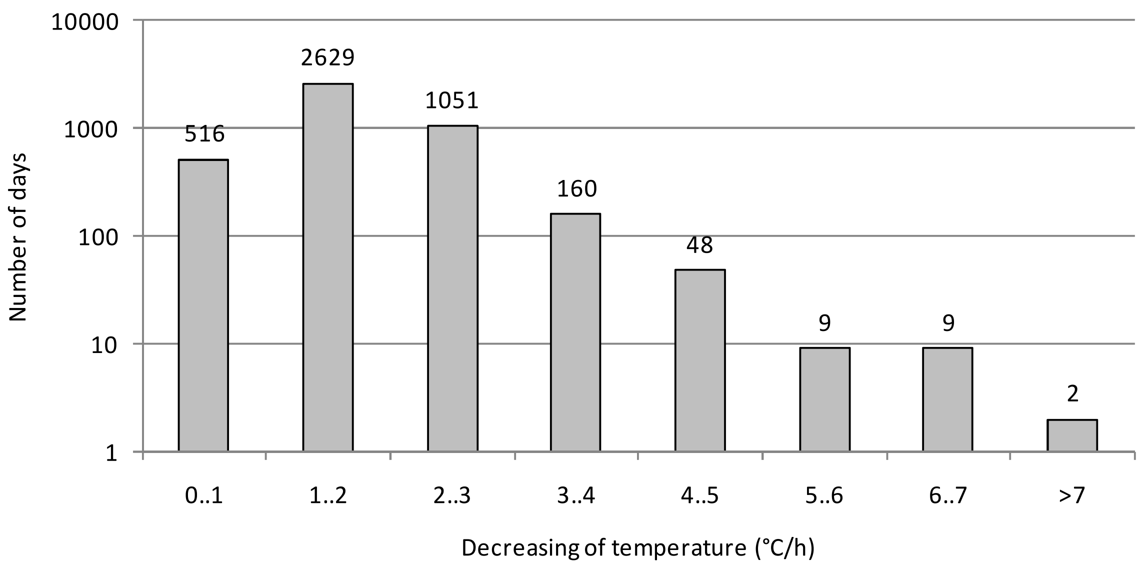

Figure 1: Occurrence of maximal daily air cooling rates (period from 1992 to 2007).

The same presentation if established in figure 2 for the temperature measured at 5 cm depth (bottom of the wearing course).

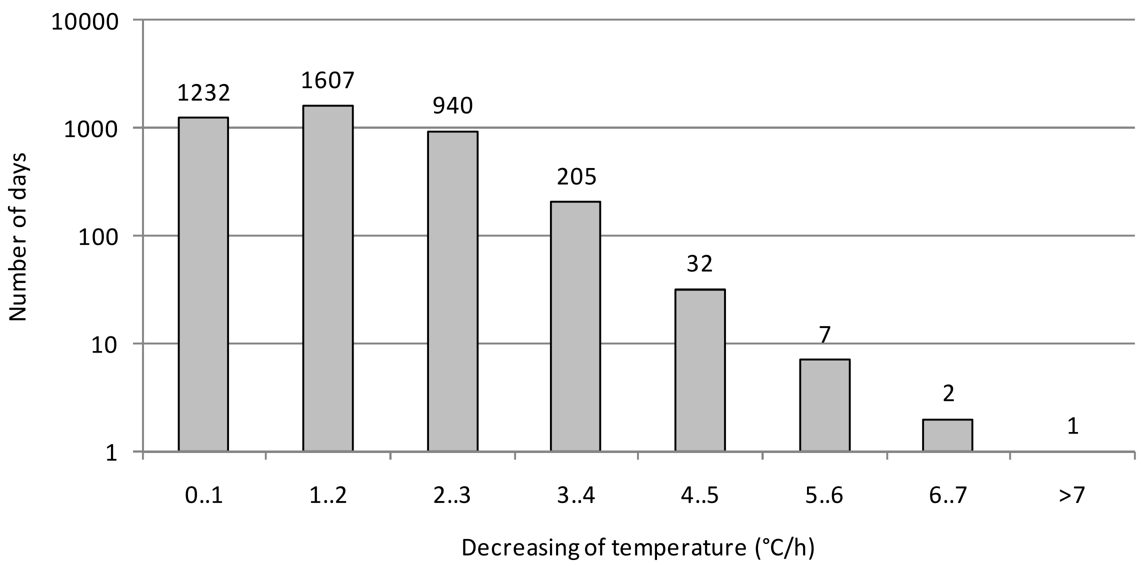

Figure 2: Occurrence of maximal daily pavement cooling rates at 5 cm depth (period from 1992 to 2007).

2.3 Pavement structure

As described in the preamble, this paper deals with 2 groups of sections:

a) Test sections of 300 m long each,
b) A regular section of 4 km long with Styrelf® 13/80 wearing course binder.

Pavement structure for the two previous groups is illustrated in figure 3 with thicknesses measured effectively on extracted cores.

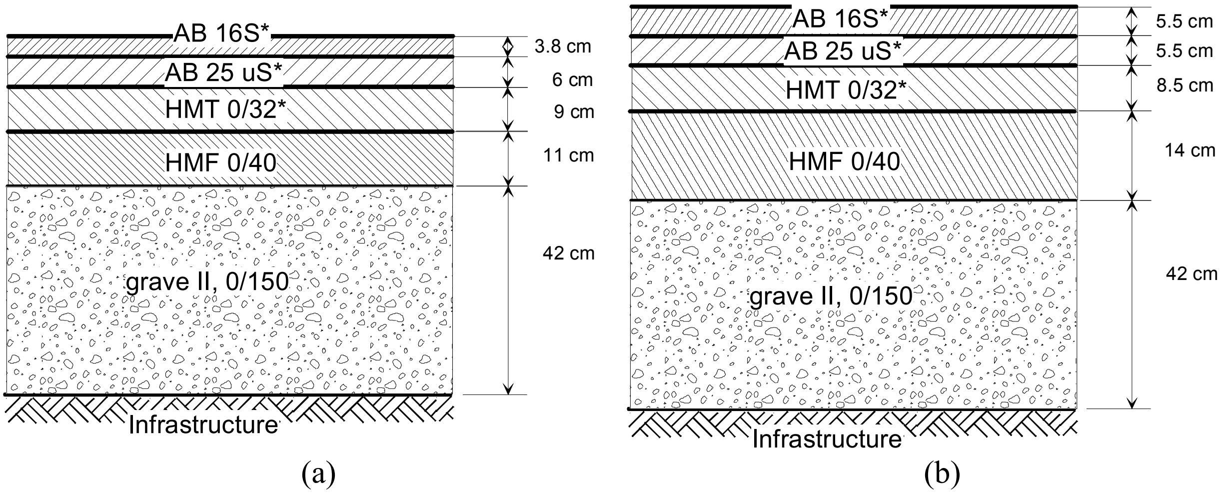

Figure 3: Pavement structure for the test sections (a) and the regular section (b).

Materials nomenclature corresponds to the previous Swiss standards with the numbers indicating the granular gradation limits using circular and not square sieves (names followed by the star: *). The AB 16S, AB 25 uS and HMT 0/32 are dense graded bituminous mixtures with decreasing binder content when going deeper in the structure. HMF 0/40 is bituminous stabilized mixture used as a subbase in combination with the unbound materials layer (grave II). More details about materials could be found in (Dumont et al., 1989).

According to structure thicknesses and materials properties, the bearing capacity is considered as very high. This is confirmed with deflection measurements using the Falling Weight Deflectometer where estimated structure lifespan is beyond 30 years which is the limit of validity of such kind of analyses.

3 SURFACE DISTRESSES AND LABORATORY TEST RESULTS

3.1 Introduction

The present section is a synthesis of a detailed analysis published in (Dumont et al., 2004). 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. The most relevant correlations are given below.

3.2 Cracking amplitude index

The cracking assessment, according to the Swiss standard SN 640 925, 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 product of the two values is normalised and expressed as a percentage. The cracking amplitude index formula is proposed as follow:

$$I_{Crack} = \left(\frac{A \times S}{9} \right) \times 100 \qquad (1)$$

3.3 Correlation between cracking amplitude index and Bending Beam Rheometer test

The Bending Beam Rheometer (BBR) test was carried out on extracted binder immediately after laying. The m-value provides a good correlation with pavement condition through the cracking amplitude index (figure 4).

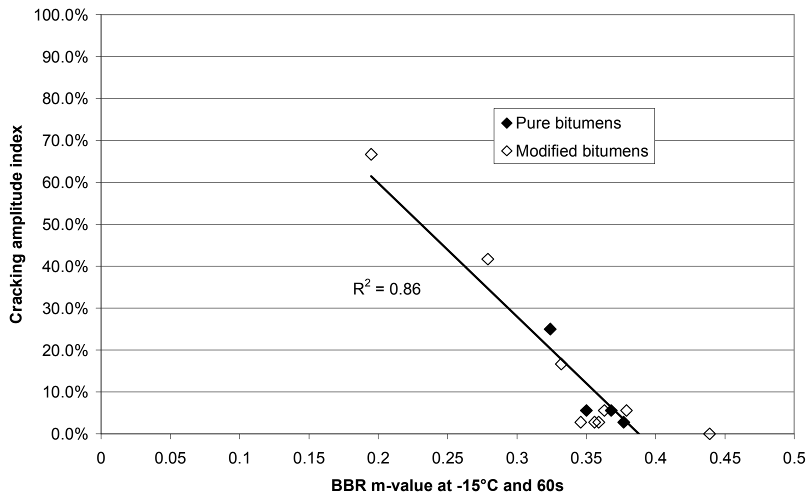

Figure 4: Cracking amplitude index versus BBR m-value for 16 test sections wearing course.

3.4 Correlation between cracking amplitude index and TSRST

The Thermal Stress Restrained Specimen Test (TSRST) and its transition temperature value (figure 5) provided the most relevant correlation between mixture tests and pavement condition. The TSRST was carried out on cored specimens after 1 year of service. This result was expected considering that this test was used to validate the BBR test.

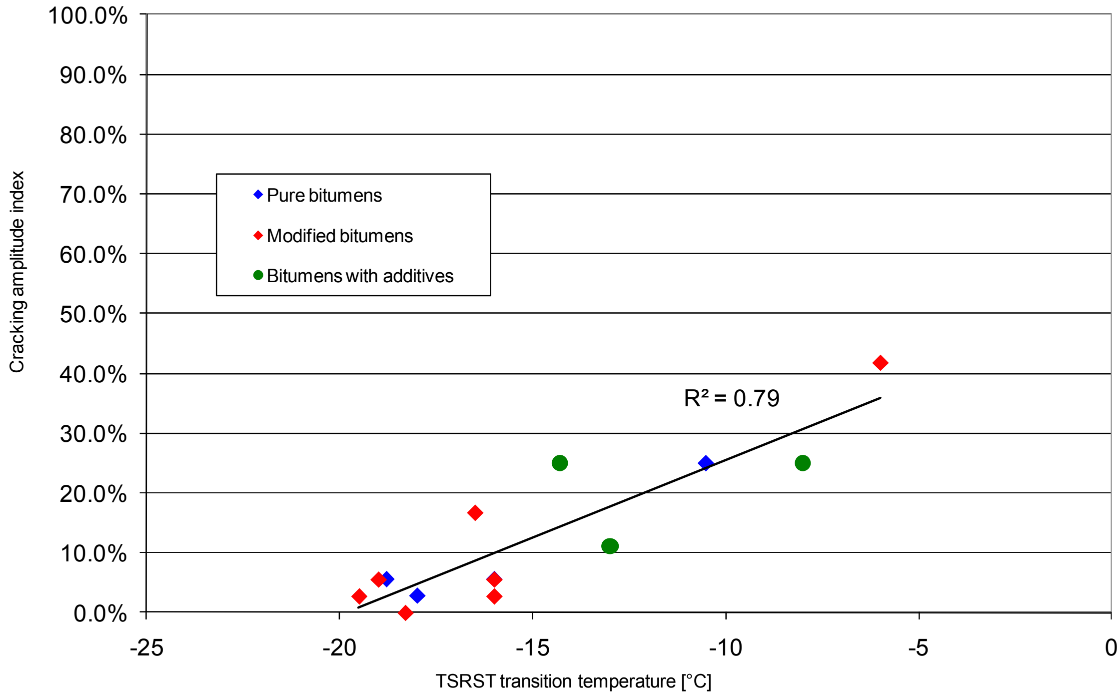

Figure 5: Cracking amplitude index versus TSRST data for 16 test sections wearing course.

3.5 Discussion

Surface pavement condition monitoring for 16 test sections demonstrated the importance of the binder properties even for high bearing capacity structures subjected to a moderate traffic. The climatic solicitations were sufficient for the initiation of thermal cracks and their propagation on most of the test sections. Thermal cracks pattern is similar to what is generally observed in regions with regular temperatures dropping under -25 °C (Haas et al., 1987, Vinson et al., 1994).

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 cross-linking 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 forward bitumen of the same penetrability grade.

4 ANALYSES OF TRAFFIC AND CLIMATE EFFECTS

4.1 Introduction

The results depicted in section 3 suggested a more detailed investigation on the reasons of the good performance of the Styrelf® 13/80 PmB. The 4 km regular section materials were selected to carry out this study. The analyses of the separate effects of traffic and climate solicitation are achieved by considering properties of materials taken from the slow lane and the emergency lane of the road section.

This section describes, for both lanes, test results on base binder properties as well as investigation of stiffness and fatigue properties of the bituminous mixtures.

4.2 Binder properties

Binder is recovered, after 19 years of service, from the slow and the emergency lanes wearing course. The PmB recovery is done according to the EN 12697-3 and the SN EN 670 403-NA standards methods which are well documented in (Pittet et al., 2002).

Binder base properties are given in table 3 in addition to the elastic recovery and force ductility results.

Table 3: Cracking extent evaluation

		Emergency lane in 2008 (without traffic)	Slow lane in 2008 (with traffic)	Samples at delivery in 1988	Prescriptions EN 14023:2005 PmB 45/80-50 Durability (RTFOT)
Pen 25 °C	[1/10mm]	46	38	75	-
Residual pen (ref. 1988)	[%]	61	51	-	≥ 60
Ring & ball temperature	[°C]	61.2	63.3	53	≥ 50
R&B temp. increase (ref. 1998)	[%]	8.2	10.3	-	≤ 8
Plasticity index PI	[-]	1.0	1.0	0.6	-
Fraass point	[°C]	-18	-12	-20	≤ -15
Plasticity interval	[°C]	79.2	75.3	73	≥ 70
Dyn. viscosity @ 170°C	[10^{-1}Pa.s]	3.4	3.4	2.6	-
Dyn. viscosity @ 150°C	[10^{-1}Pa.s]	7.0	8.0	5.3	-
Dyn. viscosity @ 130°C	[10^{-1}Pa.s]	17.7	24	13.2	-
Dyn. viscosity @ 110°C	[10^{-1}Pa.s]	66.1	79.2	not measured	-
Dyn. viscosity @ 90°C	[10^{-1}Pa.s]	365	559	173	-
Dyn. viscosity @ 60°C	[10^{-1}Pa.s]	17’496	19’343	5’453	-
Elastic recovery @ 25°C	[%]	76	69	82	≥ 50
Force ductility @ 5°C	E'j[J/cm^2]	early failure	early failure	not measured	≥ 3
Energy at failure 5°C	E'ges[J/cm^2]	11.5	11.5	15.9	-
Force ductility @ 10°C	E'j [J/cm^2]	2.21	early failure	not measured	-
Energy at failure 10°C	E'ges[J/cm^2]	6.9	7.2	not measured	-

An overall comparison between the reference samples and binders recovered from the slow and the emergency lane show the following tendencies:

- The binder after 19 years of service demonstrates very good residual properties for both the slow and the emergency lanes when compared to the initial binder. For example, residual penetration is over 50% after 19 years whereas it's around 13% for the straight forward bitumen after 14 years.
- Binder recovered from the slow lane shows a higher aging than binder recovered from the emergency lane. This tendency is observed for all binder consistency tests carried out at medium and low temperatures: Fraass point, penetration, R&B temperature and viscosities from 60 to 130 °C.
- Elastic recovery confirms the latter observation since the emergency lane binder demonstrates the higher ratio.
- The energy at failure for the force-ductility test is calculated at 5 and 10 °C and is equivalent for both recovered binders. The residual energy at failure after 19 years, which is around 72%, is also considered as very good.

4.3 Mixture stiffness modulus and fatigue properties

Stiffness moduli and fatigue properties are obtained according to the 2 points bending test (2PB-TR) carried out on trapezoidal specimens.

Stiffness modulus test is based on the EN 12697-26 standard and is the average of 6 specimens data. The test is carried out at strain amplitude of 40.10^{-6}, frequencies of 1, 3, 10, 25 and 40 Hz, and temperatures varying from -10 to +30 °C with a 5 °C step.

As observed on binders, we could notice that stiffness modulus (figure 6) is slightly higher for the slow lane when compared to the emergency lane. For instance, the difference in stiffness modulus at a temperature of 15 °C and a frequency of 10 Hz is about 17% between the slow and the emergency lanes.

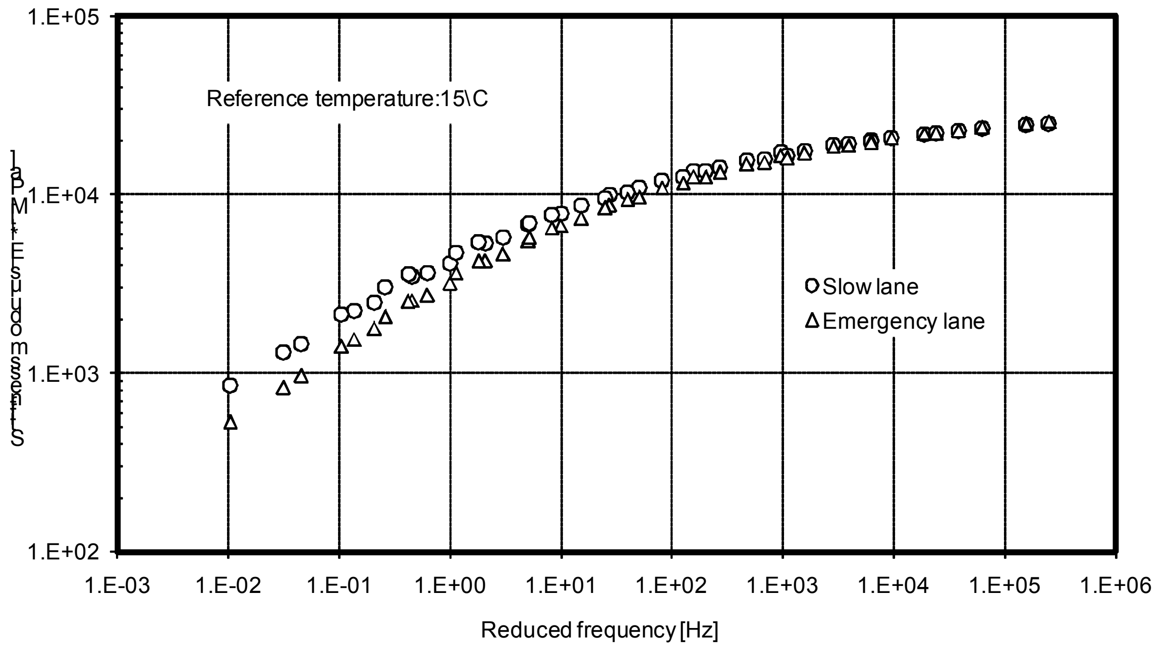

Figure 6: Master curves of stiffness modulus of materials extracted from the slow and the emergency lanes.

Fatigue test is based on the EN 12697-24 standard and is conducted at 10 °C and a frequency of 25 Hz. The fatigue curve is determined with 18 specimens data tested at 3 levels of strain amplitude. The selected levels of strain amplitude are the same for materials extracted from the slow and the emergency lanes.

Main fatigue properties are summarized in table 4 and illustrated in figure 7.

Table 4: Fatigue properties of materials extracted from the slow and the emergency lanes.

		Emergency lane in 2008	Slow lane in 2008
Geometric voids	[%]	3.0	3.3
Strain ε_6 for 10^6 cycles	[10^{-6}]	173	150
K (strain for 1 cycle)	[10^{-6}]	1429	1568
Slope	[-]	-0.15	-0.17
Correlation coefficient r^2	[-]	0.94	0.95
Initial stiffness modulus after 100 cycles at 10°C/25 Hz	[MPa]	11793	12964

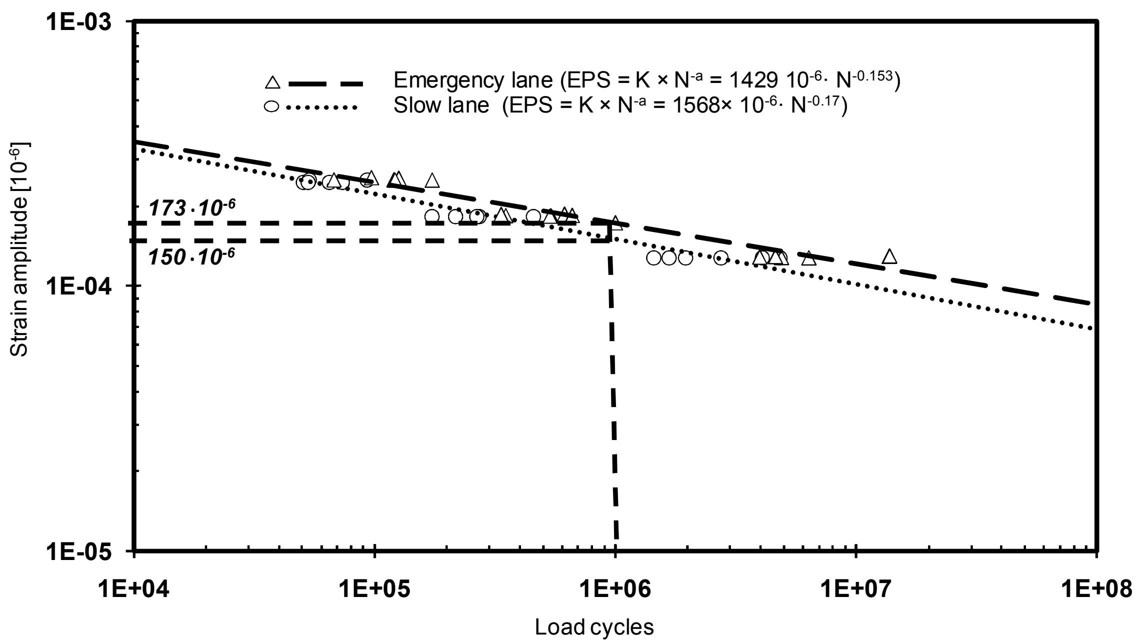

Figure 7: Wöhler's fatigue curve of materials extracted from the slow and the emergency lanes.

The emergency lane (173 micro strains for 10^6 load cycles) shows a clearly better fatigue resistance compared to the slow lane (150 micro strains for 10^6 load cycles). Expressed in term of load cycles resistance for the same strain amplitude level, the emergency lane is 2.4 times more durable against mechanical fatigue than the slow lane.

5 CONCLUSIONS

The good long term performance of the Styrelf® 13/80 binder is demonstrated thanks to a 19 years monitoring of pavement surface distresses and significant laboratory tests performance indicators.

The analyses of the properties of binders and mixtures respectively recovered and extracted from the slow and the emergency lanes demonstrated, without any contradiction between the entire tests, that the materials subjected to traffic and weather effects are more aged than those subjected only to weather. The investigation of this unexpected result is still undergoing. However, we can explain this observation by asserting the following hypotheses for the higher aging of the slow lane:

– Micro-cracks attributed to traffic increase the exposure of the material to weather,
– The dust film over the emergency lane contributes to the material protection against aging sources,
– The pumping of light fraction of bitumen from the bottom to the top of the layer under the mechanical action of traffic. This long term oils diffusion phenomenon could be more investigated in the future.

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