Influence of hydrated lime on the field performance of SMA10 mixtures containing polymer modified binder

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ABSTRACT

In literature, the beneficial effect of hydrated lime on the durability of asphalt mixtures has been demonstrated extensively, especially while performing laboratory testing. However, experimental evidence on the impact of hydrated lime in combination with the use of polymer modified bitumen (PmB) on the field performance of an asphalt pavement is rather scarce. Therefore, an initiative was taken to set up a test program of which the main objective was to gain as much as possible experience from the field.Hence, the comparative study focused on the assessment of the performance of SMA10 variants by the construction of test sections in combination with a series of laboratory tests.

The impact of hydrated lime on the performance of SMA10 variants was investigated at different stages. Prior and during the construction of the test sections, the effect of hydrated lime on the workability was monitored by carrying out either gyratory compaction tests in the laboratory or by a follow up of the in situ compaction by making use of the □-nuclear gauge. Following construction, appropriate test specimens were taken by coring in order to probe for the resistance to rutting, the water sensitivity and finally the resistance to ravelling. This paper discusses and draws conclusions from this comparative field study with respect to the use of hydrated lime in SMA10 mixtures containing a polymer modified bitumen.

Keywords: Durability, Lime, Modified Binders, Performance testing, Stone Mastic Asphalt

1. INTRODUCTION

The application of hydrated lime in order to improve the overall durability of asphalt mixtures is well known for already a long time, especially in the USA [1]. In Europe, its use is at present less common practice, although the benefits of hydrated lime as an active filler material have been reported in several countries such as France [2] or the Netherlands [3]. It is generally accepted that the positive effects of hydrated lime on the performance of asphalt mixtures are mainly related to an improvement of water sensitivity and rutting resistance [4,5,6]. Also a reduction of the negative impact of ageing of bitumen by retarding the chemical oxidation process has been described [7,8].

As compared to natural filler materials, hydrated lime is characterized by a higher dry porosity or Rigden air voids [9,10]. Consequently, the stiffening power of hydrated lime is stronger as can be demonstrated by measuring the delta Ring and Ball of mastics according to EN 13179-1. Hence, the use of 1 to 1.5% (on dry mixture) of hydrated lime results in stiffer mastics and therefore in an increase of the modulus and strength of the corresponding asphalt mixtures. However, this phenomenon may also negatively influence the workability and the compactibility of asphalt mixtures, especially in case a more viscous bitumen is utilized such as polymer modified bitumen (PmB). Latter bitumen is more and more frequently used to increase the service life of surface courses on highly trafficked roads, in particular of asphalt mixtures with a stony skeleton such as stone mastic asphalt (SMA).

A large amount of data as discussed in the literature demonstrating the positive effect of hydrated lime is based on studies carried out in the laboratory [11,12,13]. In only few reports experience with hydrated lime in the field has been described, especially over a long period [14,15,16,17,18]. Moreover, experimental evidence of the impact of hydrated lime in combination with the use of a PmB on the field performance of an asphalt pavement is rather scarce [19,20].

Therefore, a comparative study was initiated which focused on demonstrating the impact of the addition of hydrated lime on the durability of a number of SMA10 variants in the field. In order to access the performance in the field of the SMA10 variants and their evolution with time, the construction of test sections on a public road was set up. In a first step of the study, prior to the construction of the test sections, a limited number of laboratory tests were conducted to ensure a sufficient workability of the SMA10 variants including the use of hydrated lime. In a second phase, a series of tests were conducted during and shortly after the construction of the field test sections. Latter testing involved both the follow up of the compaction *in situ* as well as a series of performance tests carried out in the laboratory including the assessment of the workability, the water sensitivity, the resistance to rutting and finally the resistance to ravelling or scuffing. In order to link the laboratory study to the field to a maximal extent, it was envisioned to carry out the laboratory testing following the compaction of bulk asphalt samples taken at the finisher or originating from the road after compaction (e.g. coring). Finally, a yearly monitoring of the field performance of the completed test sections (e.g. visual inspections) is foreseen. In this paper the results of this comparative study will be presented and discussed in detail.

2. RESULTS AND DISCUSSION

2.1 Selection of SMA10 variants

As already mentioned in the introduction, a SMA10 asphalt mixture containing polymer modified bitumen (PmB) was considered as most suitable for probing for the impact of hydrated lime for the following reasons:

- A SMA10 mixture is a surface course frequently applied in Europe (also in Belgium);
- Studies showing the impact of hydrated lime on SMA with PmB's are quite limited so far;
- There is little data available demonstrating the impact of hydrated lime in SMA with PmB's in the field, in particular over a long period of service time (e.g. 10 years);
- Its nominal thickness allows performing the performance testing according to the geometrical requirements in the European standards (e.g. indirect tensile strength or ITS).

The test program was conducted on four variants of a SMA10 mixture as summarized in table 1: a SMA10 mixture with PmB not containing any hydrated lime and a SMA10 mixture with PmB where hydrated lime (1.5 w-%) was added. In addition, a third and fourth variant was included in this field study, namely a reference SMA10 mixture not containing any hydrated lime and while making use of a paving grade binder and a SMA10 mixture containing hydrated lime (1.5 w-%) but while still making use of a paving grade bitumen. In this way, both the effects of hydrated lime and/or the use of a PmB could be highlighted more clearly.

Table 1: Overview of the SMA10 test sections

# section	SMA10 variant	Length
1	SMA10 PmB 45/80-50	152.5 m

2	SMA10 PmB 45/80-50 + 1.5% $Ca(OH)_2$	145.0 m
3	SMA10 B50/70 + 1.5% $Ca(OH)_2$	127.5 m
4	SMA10 B50/70 (reference)	Remaining part of the road works: ± 1,500 m*

* Although the reference SMA10 was laid over the whole road work as tendered, within this comparative study a section 4 of similar length (150 m) to the other sections 1 – 3 was considered.

All SMA10 variants (section 1 - 3) were based on a reference SMA10 of which the initial type testing study conducted by the asphalt producer complied with the tender specifications in the Walloon Region (Qualiroutes, [21]). SMA10 variants differed by either the choice of the bituminous binder: selecting a PmB 45/80-50 (blending of SBS by high shear mixing) instead of a paving grade bitumen B50/70 and/or by replacing 1.5 w-% of the baghouse filler by hydrated lime (Supercalco 97 as supplied by Carmeuse s.a.). The bitumen content was typically 6.2%. The empirical characteristics of both bitumens are summarized in table 2.
A close collaboration with the road administration in the Walloon Region (SPW – 'Service Public de Wallonie') enabled the appropriate choice of the location of the test sections on a public road. In particular, the test sections were integrated in the construction of a new road of about 2 km long at Heppignies (N568a) in order to facilitate the access to the local airport of Charleroi (Brussels South). The construction of this new road was during the spring of 2013 in a final phase. The two base courses of AC20 were already realized before the winter 2012-2013. In 2013 only the construction of the SMA10 surface layer was planned before the summer holidays. All sections were laid over the full width of the road and at a nominal thickness of 40 mm. The construction of the test sections was carried out on June 26th 2013, permitting the subsequent coring of test samples for asphalt performance testing the next day.

Table 2: Characteristics of bituminous binders

Bitumen	Pen (0.1 mm) according to EN 1426	R&B (°C) according to EN1427
Paving grade B50/70	61	48.4
PmB 45/80-50	77	58.4

2.2 Laboratory tests conducted prior to the construction of the field trials

In order to ensure a sufficient workability of the SMA10 mixtures containing a PmB with and without the addition of hydrated lime before the construction of the field test sections, the compactibility of these mixtures was determined using NBN EN 12697-31 while making use of the constituents sampled at the asphalt plant. Moreover, the workability of the SMA10 variant while making use of a paving grade binder and with the addition of hydrated lime was measured in a similar way. It was not foreseen to evaluate the reference SMA10 mixture since the results of the ITT study were made available by the asphalt producer.
In order to obtain additional information (the gyratory compactor only provides the evolution of the geometrical bulk density) with respect to the void content both the bulk and the maximum density were also measured following 120 gyrations by hydrostatic weighing according to NBN EN 12697-6 procedure B and NBN EN 12697-5. With respect to the void content, a comparison of the above acquired test results was made with the void content as determined on the cores taken from each section in view of the determination of the water sensitivity (results discussed in § 2.4.3).
In consultation with the asphalt producer and the requirements set out in NBN EN 12697-31 SMA10 variants containing a PmB binder were compacted at 160 ± 5°C while the SMA10 variant containing a paving grade bitumen was compacted at 150 ± 5°C. For each SMA10 variant three runs were carried out up to 120 gyrations (fabrication of three gyratory test specimens). An overview of the test results is given in table 3.

Table 3: Overview of the test results on the gyratory specimens (compacted to 120 gyrations)

SMA10 variant	Air voids (geometric) %	Bulk density (hydrostatic) g/cm^3	Maximum density g/cm^3	Air voids (hydrostatic) %
SMA10 PmB 45/80-50 (Section1)	8.9 ± 0.4	2.333 ± 0.011	2.437	4.3 ± 0.5

SMA10 PmB 45/80-50 + 1.5% $Ca(OH)_2$ (Section 2)	8.5 ± 0.3	2.334 ± 0.006	2.430	4.0 ± 0.2
SMA10 B50/70 + 1.5% $Ca(OH)_2$ (Section 3)	8.4 ± 0.5	2.342 ± 0.005	2.430	3.6 ± 0.2

Based on the results summarized in table 3, no significant effect of the addition of hydrated lime on the compactibility of the SMA10 variants could be demonstrated. All air voids percentages at 120 gyrations are in line with the initial type testing results of the reference mixture (SMA10 while using a paving grade B50/70 bitumen) and comply to the tender specifications in the Walloon Region (Qualiroutes, 2011). Latter data are in good agreement with results previously published by Vansteenkiste et al. [22] indicating that no negative impact of the addition of hydrated lime on the workability of SMA mixtures could be observed despite contradictory *in situ* experience reported by some contractors.

2.3 Laboratory tests conducted during the construction of the field trials

2.3.1 Compactibility on site

The field compaction was monitored by using a γ-nuclear density gauge (Troxler Model 3450). On a single location per test section (or SMA10 variant) the evolution of the bulk density as a function of the number of roller passes was measured (a roller pass is considered as a pass of both wheels of the tandem roller compactor). Since the measurements with the γ-nuclear gauge do not provide absolute data with respect to void content, only relative comparative information was gathered. In parallel, the evolution of the temperature of the SMA10 variants during compaction was determined while using a temperature probe which was inserted within the asphalt layer. Additionally, the temperature of the bulk mixtures was also measured in the truck while unloading using a penetration thermometer.

The results of the temperature measurements are summarized in table 4. Generally, a very good correlation between the first reading of the temperature probe inserted within the SMA10 layer and the temperature of the bulk mixture as measured in the truck while unloading was established.

A typical result (section 2) of the follow up of the field compaction in combination with the evolution of the temperature during the construction of each section is illustrated in figure 1. For a discussion of the results in terms of the relative degree of compaction the reader is referred to § 2.3.2.

Table 4: Overview of the *in situ* temperature measurements

SMA10 variant	**First reading by temperature probe inserted in SMA10 layer**	**Temperature of bulk mixture in truck while unloading**
SMA10 PmB 45/80-50 (Section 1)	169.2°C	168.4°C
SMA10 PmB 45/80-50 + 1.5% $Ca(OH)_2$ (Section 2)	159.0°C	160.0°C
SMA10 B50/70 + 1.5% $Ca(OH)_2$ (Section 3)	162.8°C	156.0°C*
SMA10 B50/70 reference (Section 4)	167.2°C	168.0°C

* A subsequent measurement in the second truck resulted in a temperature of 168.1°C.

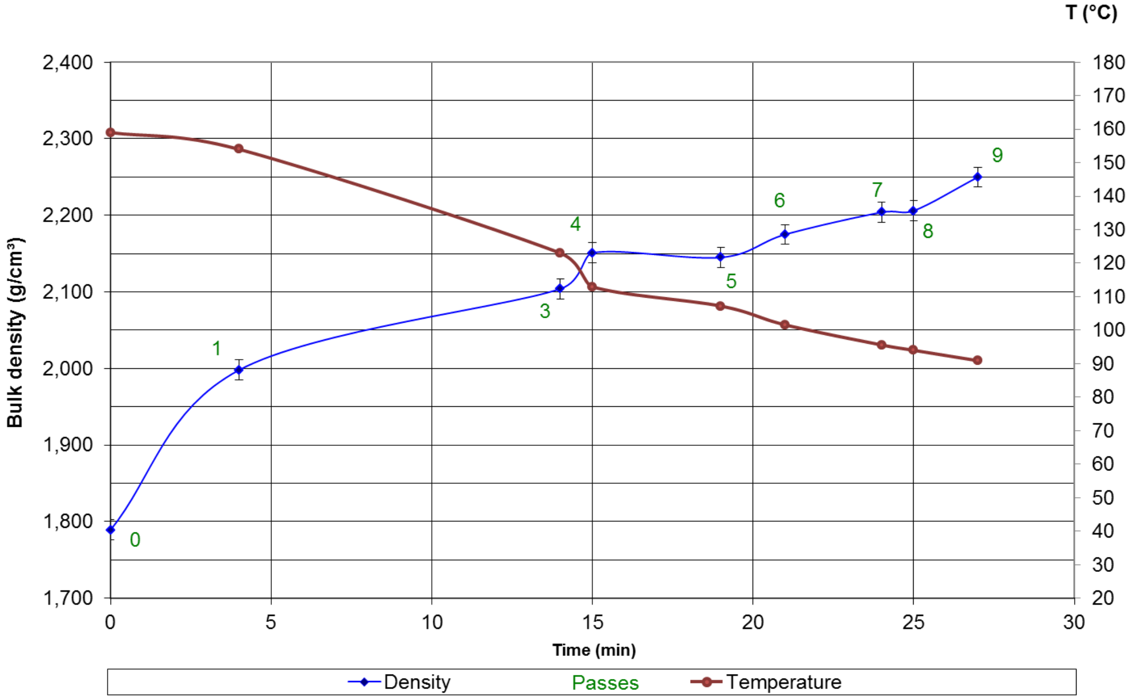

Figure 1: The evolution of both the bulk density in function of the compaction as well as the temperature as a function of time for section 2: SMA10 PmB 45/80-50 + 1.5% $Ca(OH)_2$

2.3.2 Uniformity of compaction in the field

The use of the γ-nuclear gauge also allowed to investigate the uniformity of compaction within each section. Given a length of ± 150 m for each section was available (except for the reference section), the measurement of the relative bulk density was carried out at 6 or 7 different locations. In this way, one acquired insight in the homogeneity of the field compaction.

A summary of the results of the γ-nuclear density gauge is given in table 5 below. In latter table both the bulk densities are listed at each point (as defined by an exact X and Y coordinate for each section) as well as the corresponding relative degree of compaction. The target value corresponds to the density as measured following a gyratory compaction in the laboratory at 120 gyrations of the corresponding SMA10 variant.

In order to be able to discuss possible differences in relative degree in compaction as probed be the γ-nuclear density gauge, a number of ten repeated measurements on the same location were conducted in section 1 (prior to all other γ-nuclear density gauge measurements carried out during the field trials). From the result of these measurements a σ-value = 0.013 g/cm³ was determined. This σ-value corresponds to a difference of 0.6% in the relative degree of compaction.

The availability of the data summarized in table 5 helped to select the most appropriate location for field coring in a later stage (see §2.4.3). This was of particular importance with respect to the determination of the water sensitivity. The result of the latter performance related test is highly sensitive to the void content of the test specimens, and therefore directly correlated to the degree of compaction. In order to maximize the risk in terms of water sensitivity, cores were always taken at the location characterized by the lowest relative compaction degree (= highest air voids content); see table 5.

Table 5: Summary of the γ-nuclear gauge measurements while probing for the homogeneity of field compaction for each section. Locations in grey shade were identified as appropriate for coring the required test specimens for carrying out the water sensitivity test

Section 1 SMA10 PmB 45/80-50			**Target: 2.221g/cm³**	
Point	X (m)	Y (m)	Density (g/cm³)	% target
1.1	20	1.30	2.303	103.7
1.2	40	1.36	2.272	102.3
1.3	60	1.33	2.290	103.1

1.4	80	1.24	2.206	99.3
1.5	100	1.37	2.293	103.2
1.6	120	1.34	2.288	103.0
1.7	140	1.18	2.295	103.3
			average	102.6 ± 0.5
Section 2 SMA10 PmB 45/80-50 + hydrated lime			**Target: 2.225g/cm^3**	
Point	X (m)	Y (m)	Density (g/cm^3)	% target
2.1	18	1.41	2.243	100.8
2.2	40	1.26	2.252	101.2
2.3	60	1.30	2.319	104.2
2.4	80	1.34	2.254	101.3
2.5	100	1.30	2.244	100.9
2.6	120	1.30	2.243	100.8
2.7	140	1.24	2.187	98.3
			Average	101.5 ± 1.3
Section 3 SMA10 B50/70 + hydrated lime			**Target: 2.226g/cm^3**	
Point	X (m)	Y (m)	Density (g/cm^3)	% target
3.1	20	1.35	2.330	104.7
3.2	38	1.30	2.256	101.3
3.3	60	1.25	2.193	98.5
3.4	80	1.48	2.304	103.5
3.5	100	1.36	2.281	102.5
3.6	120	1.45	2.324	104.4
			Average	102.5 ± 2.3
Section 4 SMA10 B50/70 (reference)			**Target: 2.226g/cm^3**	
Point	X (m)	Y (m)	Density (g/cm^3)	% target
4.1	18	1.41	2.325	104.4
4.2	40	1.38	2.172	97.6
4.3	60	1.29	2.297	103.2
4.4	80	1.35	2.307	103.6
4.5	100	1.11	2.219	99.7
4.6	120	nd	2.313	104.0
			Average	102.1 ± 2.8

Based on the obtained results, the following conclusions can be put forward:

- All relative densities in the field exceed 97%. Therefore, field compaction can be considered as very good;
- With respect to the uniformity of the compaction within each section, the following conclusions can be made:
  - The compaction of section 1 can be considered as quite uniform: spread of 0.5% < 0.6% (σ-value from repeated measurements) although at location 1.4 the relative degree of compaction is low (99.3%);
  - The compaction of section 2 is quite homogeneous except for two locations: a low relative degree of compaction was observed at location 2.7 (98.3%) and a high relative degree of compaction was measured at location 2.3 (104.2%);
  - The relative degree of compaction of section 3 is characterized by a higher variability: spread of 2.3% as compared to 0.6% (σ-value from repeated measurements). The section shows both locations with a high (e.g. point 3.1 or 3.6) as well as a low relative degree of compaction (e.g. point 3.3);
  - The relative degree of compaction of section 4 (reference) is characterized by the highest variability: spread of 2.8% as compared to 0.6% (σ-value from repeated measurements). The section shows both locations with a high (e.g. point 4.1 or 4.6) as well as a low relative degree of compaction (e.g. point 4.2).

2.4 Performance testing on SMA10 variants following shortly the construction of the field trials

As already pointed out in the introduction, in a second phase of the study a series of performance related tests were conducted shortly after the construction of the field test sections. Latter testing included the assessment of the workability, the water sensitivity, the resistance to rutting and finally the resistance to ravelling by traffic.

2.4.1 *Compactibility*

The compactibility of the SMA10 mixtures was determined while using NBN EN 12697-31. In order to obtain additional information (the gyratory compactor only provides the evolution of the geometrical bulk density) with respect to the void content both the bulk and the maximum density were measured by hydrostatic weighing according to NBN EN 12697-6 procedure B and NBN EN 12697-5.
The test was carried out while making use of the bulk mixtures sampled at the asphalt plant from the trucks departing to the corresponding test sections. Bulk samples were reheated to the appropriate temperature prior to carrying out the gyratory compaction tests: SMA10 variants containing PmB's were compacted at 160 ± 5°C while the SMA10 variants containing a paving grade bitumen were compacted at 150 ± 5°C. For each SMA10 variant three runs were carried out up to 120 gyrations (fabrication of three gyratory test specimens). An overview of the test results is given in Table 6.

Table 6: Overview of the test results on the gyratory specimens (compacted to 120 gyrations) produced with bulk mixtures sampled at the plant

SMA10 variant	Air voids (geometric) %	Bulk density (hydrostatic) g/cm^3	Maximum density g/cm^3	Air voids (hydrostatic) %
SMA10 PmB 45/80-50 (Section 1)	8.8 ± 0.2	2.338 ± 0.002	2.435	4.0 ± 0.1
SMA10 PmB 45/80-50 + 1.5% $Ca(OH)_2$ (Section 2)	8.1 ± 0.2	2.346 ± 0.003	2.433	3.6 ± 0.1
SMA10 B50/70 + 1.5% $Ca(OH)_2$ (Section 3)	9.5 ± 0.3	2.327 ± 0.001	2.438	4.6 ± 0.1
SMA10 B50/70 reference (Section 4)	8.0 ± 0.4	2.347 ± 0.009	2.437	3.7 ± 0.4

Based on the results summarized in table 6, a "negative" effect on the compactibility of the addition of hydrated lime could only be observed while comparing the SMA10 variants comprising a paving grade bitumen B50/70: air voids at 120 gyration 8.0% → 9.5%. Latter effect which could be attributed to the stiffening of the corresponding mastic could not be observed in the case a PmB was used. On the contrary, even a small decrease of the air void content was observed. Air voids percentages at 120 gyrations are in line with the results obtained prior to the field trials and comply with the tender specifications in the Walloon Region.

2.4.2 *Resistance to rutting*

The resistance to rutting was assessed by the wheel tracking test according to NBN EN 12697-22 while using the large size device. The tests were performed at a temperature of 50°C and up to 30,000 cycles (standard test conditions in Belgium). Test specimens were obtained from the road by coring specimens of 400 cm^2 (∅ 220 mm) the day following construction. Six cores were taken from each section. The cores are sawn to rectangular samples which are subsequently fixed in the testing molds using plaster of Paris. Three cores are combined to form one test specimen and two test specimens are needed to perform one wheel tracking test, hence the need for six large cores per test section. The results for all four sections are illustrated in figure 2. The vertical bars represent the results of the two individual test specimens and the full lines are the average results.

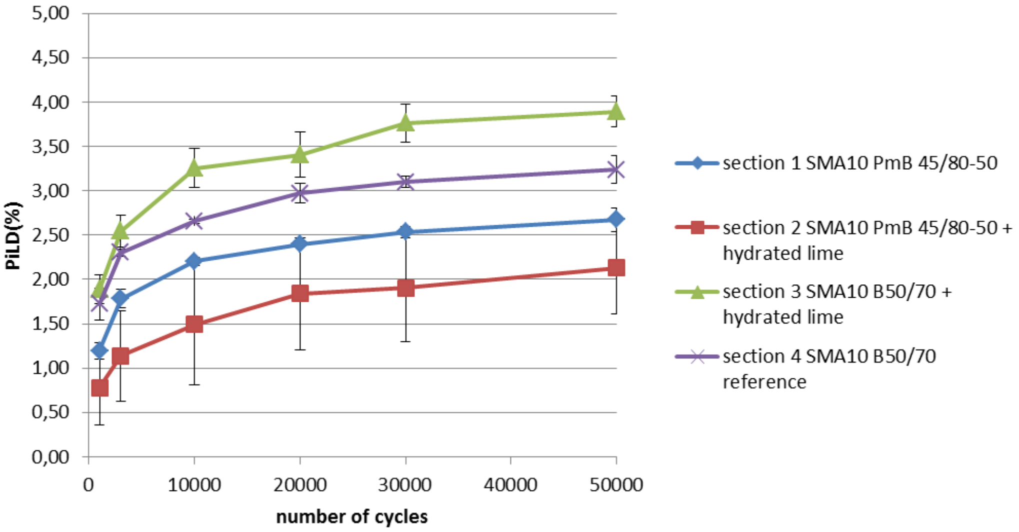

Figure 2: Results of the wheel tracking tests for all four SMA10 variants

Based on the results visualized in figure 2, the following conclusions can be put forward:

- All SMA10 variants are characterized by a PiLD < 5% at 30,000 cycles and therefore all mixtures relate to category P5 (= very good resistance to rutting);
- SMA10 variants containing a PmB are performing better in comparison with those comprising a paving grade bitumen B50/70 as could be anticipated;
- The effect of the addition of hydrated lime is difficult to demonstrate given the rather small differences in test results and taking into account the precision of the test method.

2.4.3 Water sensitivity

The water sensitivity of SMA10 asphalt mixtures was evaluated by indirect tensile strength (ITS) measurements carried out before and after conditioning in water, using the test method NBN EN 12697-12 in combination with NBN EN 12697-23. The indirect tensile tests were performed at 15°C as required in NBN EN 13108-20 (type testing of bituminous mixtures). Routinely, the air void content of the test specimens was calculated according to NBN EN 12697-8 following the determination of the maximum density according to NBN EN 12697-5.

Table 7: Results of the water sensitivity tests for all SMA10 variants

SMA10 variant	**Before conditioning**		**After conditioning**		***ITS-Ratio (%)***
	ITS (MPa)	***Air voids (%)***	***ITS (MPa)***	***Air voids (%)***	
SMA-10 PmB 45/80-50 (Section 1)	1.54 ± 0.08	5.3 ± 0.6	1.47 ± 0.02	5.8 ± 0.2	96 ± 3
SMA10 PmB 45/80-50 + 1.5% $Ca(OH)_2$ (Section 2)	1.45 ± 0.03	6.8 ± 0.6	1.36 ± 0.08	6.6 ± 0.4	94 ± 3
SMA10 B50/70 + 1.5% $Ca(OH)_2$ (Section 3)	1.38 ± 0.13	8.2 ± 0.7	1.38 ± 0.06	7.9 ± 0.8	100 ± 6
SMA10 B50/70 reference (Section 4)	1.49 ± 0.06	3.7 ± 0.1	1.50 ± 0.11	3.5 ± 0.1	101 ± 5

The test was conducted on cylindrical test specimens (∅100 mm) obtained by coring in the field (carried out by the contractor) the day following the construction. Six cores were taken from each section. The most appropriate location for coring (lowest compaction giving rise to highest air void content) was based on the test results related to the uniformity of field compaction (see § 2.3.2 for the determination of the location, table 5). An overview of the test results for water sensitivity is given in table 7.

Examination of the results summarized in Table 7 leads to the following conclusions:

- All SMA10 variants are characterized by a very high ITS-ratio and are therefore characterized by a very low or even no water sensitivity;
- The effect of the addition of hydrated lime cannot be demonstrated since differences in test results are not significant taking into account the calculated errors;
- The stiffening effect of hydrated lime is clearly reflected in the air void content of the cores originating from the field in case a paving grade bitumen has been used (e.g. 3.7% → 8.2%) but only to a minor extent when a PmB was utilized (e.g. 5.3% → 6.8%);
- The air voids of the field cores are significantly higher in comparison with the values obtained following gyratory compaction as summarized in table 6 (e.g. for section 3: 4.6 ± 0.1% → 8.0 ± 0.7%) except for the reference section where similar air voids were determined. However, one should take into account that field cores were taken at the lowest relative compaction degree in order to maximize risks with respect to water sensitivity. Moreover, the comparison is further hampered by the difference in temperature in the field and during the gyratory compaction tests (see table 4).

2.4.4 Resistance to ravelling

Field experience shows that aggregate loss at the surface or ravelling is a frequently observed damage phenomenon of asphalt mixtures with a stony skeleton. Porous Asphalt is highly sensitive, but SMA may also be sensitive in case of high void contents or poor adhesion between the bitumen and aggregate. [23,24]. Consequently, in this comparative study, it was also the objective to investigate the impact of hydrated lime and/or the use of a PmB on the resistance to ravelling by traffic of a series of SMA10 variants.
The ravelling due to traffic induced shear forces (also called “scuffing” forces) was probed for while using a procedure based on a new European draft Test Specification (TS) prCEN/TS 12697-50 ‘Resistance to Scuffing’ as developed recently by the task group CEN TC227 WG1/TG2 “Test methods for bituminous mixtures”. Latter TS describes four different test methods for determining the resistance to scuffing of asphalt mixtures. These methods consist of applying high traffic induced shear stresses to the surface of a test slab and measuring the loss of material which occurs due to these shear stresses. In this study the ‘Darmstadt Scuffing Device’ (DSD) as described in Annex B of prCEN/TS 12697-50 has been used (see figure 3). In this test one has made use of a slab of compacted asphalt starting from sampled bulk mixtures taken at the asphalt plant. The fabrication of the slabs was carried out by roller compaction according to NBN EN 12697-33. Therefore, bulk samples were reheated to the appropriate temperature prior to carrying out the roller compaction: SMA10 variants containing PmB’s were compacted at 160 ± 5°C while the SMA10 variants containing a paving grade binder were compacted at 150 ± 5°C.

Figure 3: Experimental set-up of the ‘Darmstadt Scuffing Device’ (DSD) equipment at BRRC

Following their fabrication, the test slabs were fixed on a horizontal table. This table performs a combination of translations and rotations in the horizontal plane, while the wheel is pressed onto the plate surface under a vertical load of 1 kN. Due to the resulting shear stresses, material loss will occur from the surface of the slab. This material loss depends on the resistance to scuffing of the tested asphalt mixture: the higher the resistance, the less material will disappear. The tests were conducted at both room temperature (27°C at the time of testing) (Figure 4) as well as at 40°C (Figure 5). In latter case, slabs were conditioned at 40°C in an oven prior to testing.

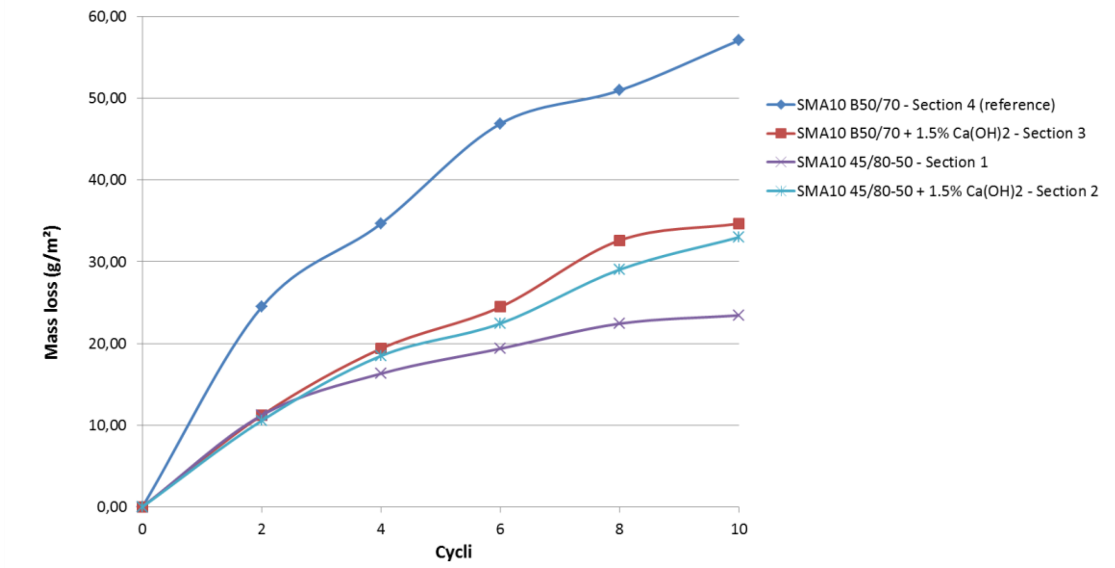

Figure 4: Comparative results of the scuffing tests conducted at 27°C

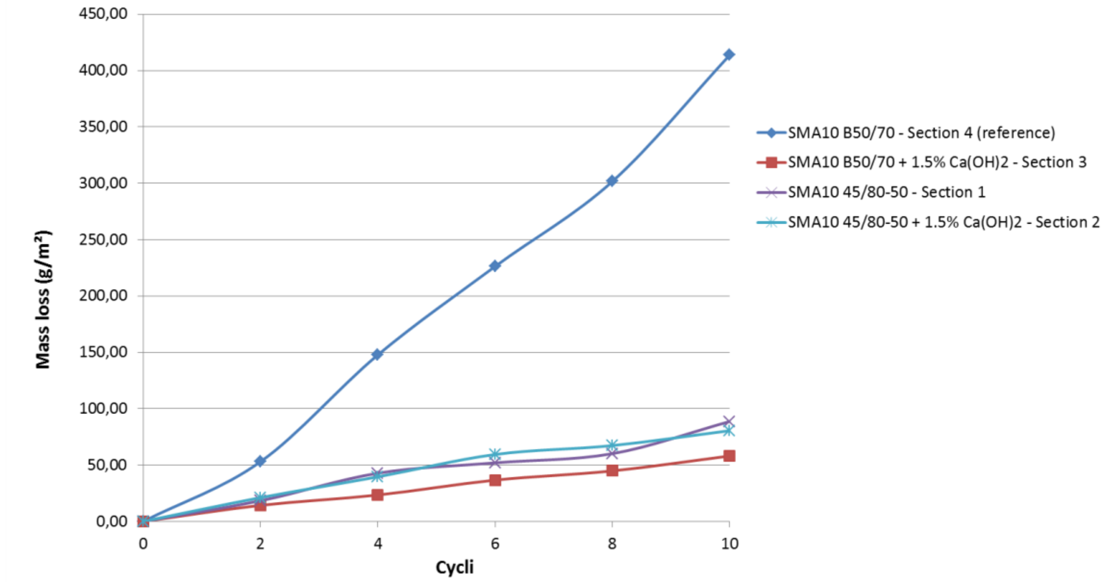

Figure 5: Comparative results of the scuffing tests conducted at 40°C

Based on the results visualized in the Figures 4 and 5, the following findings can be highlighted:

- When the ravelling test is conducted at 27°C, the mass loss measured is small for all SMA10 variants as could be expected for a SMA10 mixture;
- The resistance to ravelling is lower for the reference SMA10 variant comprising of a paving grade binder B50/70 and without any addition of hydrated lime as compared to the other SMA10 variants. No difference could be demonstrated between the other three SMA10 variants;
- When the tests are conducted at 40°C, the mass losses increase when compared to the results obtained at 27°C. In the case of the reference SMA10 variant this effect is spectacular;
- At 40°C no difference could be established between the SMA10 variants containing either a PmB binder and/or hydrated lime.

3. CONCLUSIONS AND FUTURE PERSPECTIVES

In this paper, the results of a comparative study investigating the impact of the addition of hydrated lime in combination with the use of polymer modified bitumen on the performance behaviour of SMA10 mixtures were discussed. The objective of the test program was to gain as much as possible experience from the field. Based on the results acquired, the following conclusions can be drawn:

- The compactibility of a series of SMA10 variants as probed by gyratory compaction test in the laboratory prior to the construction of the corresponding test sections indicated a good workability of all mixtures. No negative effect of the use of hydrated lime was demonstrated also in combination with the application of a PmB binder. A similar observation was made while using bulk materials sampled at the asphalt production plant during the construction of the test sections.
- The *in situ* measurement of the compaction by use of the γ-nuclear gauge confirmed the very good compaction in the field for all SMA10 variants. Generally, the uniformity of the compaction within each test section can be considered as high. Surprisingly, the reference section which did not include a polymer modified binder nor hydrated lime was characterized by the largest variability;
- Performance testing following the construction of the test sections showed that all SMA10 variants were characterized by a very low water sensitivity and a good resistance to rutting;
- The results of scuffing tests showed a positive effect of the use of hydrated lime on the resistance to ravelling in case of the B50/70 binder, especially when the test was conducted at higher temperature (e.g. 40°C).

At the time this paper was drafted, only a relatively short period of about 2 years following the construction of the test sections had elapsed. As anticipated on the basis of the results of the testing carried out at the different stages of this comparative study, at present the field performance of the SMA10 variants can be considered to be excellent independently of both the nature of the bituminous binder used as well as the addition of hydrated lime. No premature distresses could be observed. It is foreseen to continue the monitoring campaign in the future over a period of at least 10 years in order to follow up the evolution of the performance of the SMA10 variants.

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