# The use of hydrated lime in the formulation of asphalt mixtures: European case studies

**Didier Lesueur[1, a], Christophe Denayer[2, b], Hans-Josef Ritter[3, c], Christof Kunesch[4, d], Slawomir Gasiorowski[5, e], Alberto d'Alto[6, f]**

[1] *NBD Department, Lhoist, Paris, France*
[2] *Carmeuse Group, Seilles, Belgium*
[3] *Federation of German Lime Industry (BVK), Köln, Germany*
[4] *Wopfinger Baustoffindustrie GmbH, Waldegg, Austria*
[5] *Lhoist, Krakow, Poland*
[6] *Unicalce SpA, Lecco, Italy*

[a] didier.lesueur@lhoist.com
[b] christophe.denayer@carmeuse.com
[c] hans-josef.ritter@kalk.de
[d] c.kunesch@wopfinger.baumit.com
[e] Slawomir.Gasiorowski@Lhoist.com
[f] adalto@unicalce.it

**ABSTRACT**

*Hydrated lime is being increasingly used in Europe as a multifunctional additive for asphalt mixtures. Reasons for this have been thoroughly reviewed and explained in recent years, showing that the main benefits lie in the improvement in resistance to moisture damage, slowing-down of bitumen aging and improved mechanical properties. These combined effects lead to an increased durability of the mixtures. In this paper, examples are given of how these functionalities are being used in the formulation of asphalt mixtures in several European countries. Resistance to moisture damage is exemplified in the French and Belgian contexts, with respectively a case study showing the use of Hydrated Lime modified Asphalt Concrete (AC) in the severe conditions of continental road mountains (tough winter, curves) and in the case of Stone Mastic Asphalt (SMA) mixtures. Aging resistance is highlighted in the framework of German and Polish case studies on AC and SMA mixtures respectively. Finally, the effect of binder stiffening is explained in the context of Austrian (AC) and Italian (Porous Asphalt, SMA) examples. These various case studies all concur to the fact that the use of an active filler such as hydrated lime makes it possible for the formulator to have an efficient way to adjust asphalt mixtures properties, besides the more usual choices of aggregate and binder.*

**Keywords:** Asphalt, Design Mix, Durability, Lime

## 1. INTRODUCTION

Hydrated lime has been known as an additive for asphalt mixtures from their very beginning [1]. It experienced a strong interest during the 1970s in the USA, partly as a consequence of a general decrease in bitumen quality due to the petroleum crisis of 1973, when moisture damage and frost became some of the most pressing pavement failure modes of the time. Hydrated lime was observed to be the most effective additive [2] and, as a consequence, it is now specified in many States and it is estimated that 40 Mt of the asphalt mixtures produced yearly in the USA now hold hydrated lime.
Given its extensive use in the past 40 years in the USA, hydrated lime has been seen to be more than a moisture damage additive [1,3]. Hydrated lime is known to reduce chemical ageing of the bitumen [1,3,4,5,6]. Furthermore, it stiffens the mastic more than normal mineral filler [1,3,4,5,6], an effect that is only observed above room temperature [1,6]. This impacts the mechanical properties of the asphalt mixture, and if strength and modulus are seen to be modified by hydrated lime addition for a little more than half of the mix formulas, it improves the rutting resistance in about 75% of the mix formulas [1]. In all cases, most of the studies focus on hydrated lime contents of 1-1.5%, and these effects are generally more pronounced for higher hydrated lime contents. Finally, the few published studies on fatigue resistance indicate that hydrated lime improves the fatigue resistance of asphalt mixtures in 77% of the cases. In line with the observation that hydrated lime does not exhibit a higher stiffening effect than mineral filler at low temperature, no negative effect on the thermal cracking resistance is reported in the literature [1,6]. The mechanisms explaining why hydrated lime is so effective in modifying asphalt mixture have been detailed [6].
Given that the mixture properties improved by lime modification impact the durability of asphalt mixtures, the use of hydrated lime has a strong influence on asphalt mixtures durability [3,7]. North American State agencies estimate that hydrated lime increases the durability of asphalt mixtures by 2 to 10 years, that is by 20 to 50 % [3]. The European experience is not yet as developed as in the USA, but the beneficial effects of hydrated lime on asphalt mixture durability have also been largely reported. As an example, the French Northern motorway company, SANEF, currently specifies hydrated lime in the surface courses of its network, because they observed that hydrated lime modified asphalt mixture have a 20-25% longer durability [8]. Similar observations led the Netherlands to specify hydrated lime in porous asphalt [9], a type of mix that now covers almost 90% of the highways in the country. As a result, hydrated lime is being increasingly used in asphalt mixtures in most European countries, in particular Austria, France, the Netherlands, Poland and Switzerland.
Still, reasons to use hydrated lime seem to be largely unknown to most asphalt formulators in Europe, and only experts with a direct experience with it know of all of its benefits. Therefore, this article tries to show how the functionalities of hydrated lime can be used in practice in order to improve asphalt mixtures. The use of an active filler, i.e. hydrated lime, can be seen as a new tool for the formulator in order to adjust asphalt properties, in addition to the more usual choices of aggregate and binder.
More precisely, hydrated lime is now seen as a multifunctional additive that increases the durability of asphalt mixes through its improvement of [1-7]:

- The resistance to moisture damage and frost,
- The resistance to chemical ageing,
- The stiffening of the binder, with consequences on the mechanical properties, in particular an improved rutting resistance, but also on binder drainage, that can be reduced for example in Porous Asphalt.

All of these functionalities are now reviewed based on European case studies.

## 2. RESISTANCE TO MOISTURE DAMAGE AND FROST

The effect of hydrated lime on the moisture resistance of asphalt mixtures is exemplified by the following study performed at the Epsilon laboratory (France). The study was made with granite aggregate from a local quarry in the Vosges area. The mix formula contained a relatively high amount of added filler (3.78% based on mixture), which made it possible to to substitute part of it by increasing amounts of hydrated lime. The lime was a calcic hydrated lime with more than 90% CaO + MgO (CL 90 S according to EN 459-1). It was added at 1 or 2% of the aggregate.

**Table 1: Mix design for the French AC based on granite aggregate (% weight based on total mix).**

| Component | Reference AC | AC with 1 % lime | AC with 2 % lime |
|---|---|---|---|
| 0/4 Sand | 35.88 | 35.88 | 35.88 |
| 4/6 Aggregate | 7.55 | 7.55 | 7.55 |
| 6/10 Aggregate | 47.21 | 47.21 | 47.21 |
| Filler | 3.78 | 2.83 | 1.89 |
| Hydrated Lime | - | 0.94 | 1.89 |
| 50/70 Bitumen | 5.57 | 5.57 | 5.57 |

The samples were compacted to 10% air voids by static compaction following EN 12697-12 method B. The compressive strength was measured on dry specimens and on wet specimens after 2 types of storage conditions:

- Standard EN 12697-12 method B storage (known as the “Duriez” procedure in France) consisting in 7 days in a 18°C water bath,
- Severe conditions consisting in 14 days in a 40°C water bath containing 2% NaCl.

These last conditions were determined from previous works to be more aggressive than the standard “Duriez” procedure thanks to a longer time, higher temperature and the presence of deicing salt. The 2% content was chosen because it was said to be the most severe salt content in a Canadian study [10]. Note that in a former study, it was observed that the presence of salts did not impact the wet storage compressive strength after 3 or 7 days at 20 or 40°C [11]. Although not shown here, this study confirmed that the presence of salts did not affect the wet compressive strength after 7 days at 40°C, which remained close to that also measured after 14 days without salts. Still, it clearly appears that the presence of salts had a strong impact on the wet compressive strength of the reference sample after 14 days of storage (Figure 1). Clearly, the detrimental effect of salts need time to develop and 7 days at 40°C are not enough to have it materialize.

A/ Standard “Duriez” storage (7 days, 18°C) B/ Severe storage (14 days, 40°C, 2% NaCl)

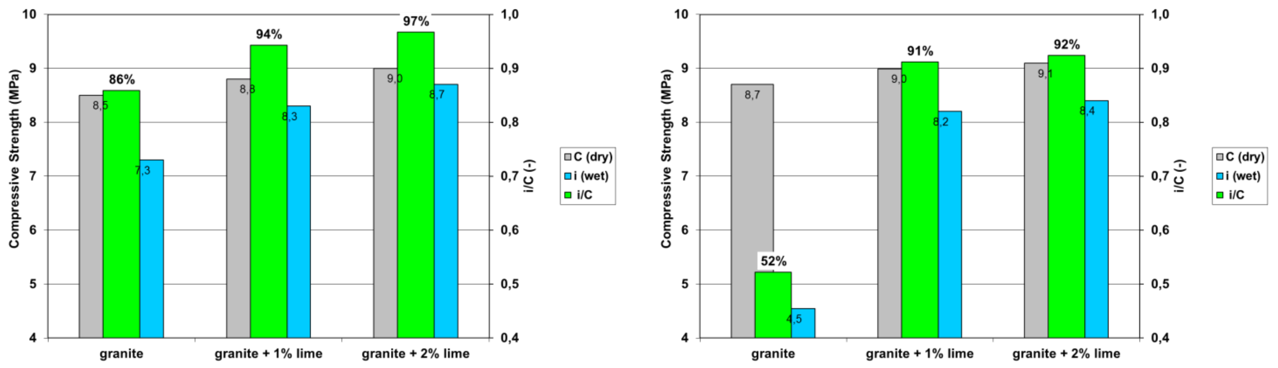


**Figure 1: Compressive strength of dry (C) / wet (i) specimens and retained resistance (i/C) for an AC made with with 0, 1 and 2% hydrated lime with granite aggregate under A: standard “Duriez” storage conditions (7 days in a 18°C water bath) B: severe storage conditions (14 days in a 40°C water bath containing 2% NaCl)**

The results are shown in Figure 1. The addition of increasing amounts of hydrated lime could be perceived by the standard procedure (Figure 1A), but the difference compared to the reference remain small, especially given that the reference material already passes the most stringent specifications (i/C > 80%). However, the severe conditions had a strong impact on the retained resistance of the reference sample, when the mixtures with lime were almost not impacted by the storage (Figure 1B).

These results on regular AC can be compared with published data from the Belgian Road Research Center on Stone Mastic Asphalt (SMA) based on Belgian river gravel with and without hydrated lime [12]. The study was made in the laboratory with 6% 50/70 Venezuelan bitumen on a SMA 10 whose composition was positioned in the worst possible conditions as far as moisture resistance was concerned (binder content on the lowest possible hand and choice of aggregate), but still complying with local composition guidelines, in order to enhance the moisture damage (Table 2).

**Table 2: Mix design for the Belgian SMA 10 (%weight based on total mix). The hydrated lime was added by using a mixed filler Ka5 or Ka20 (according to EN 13043), i.e. containing respectively 5 or 20 wt.% hydrated lime. Data from [12].**

| Component | Reference SMA | SMA with 0.5 % lime | SMA with 2 % lime |
|---|---|---|---|
| 0/4 Sand | 15.9 | 15.9 | 15.9 |
| 4/6 Aggregate | 11.5 | 11.5 | 11.5 |
| 6/10 Aggregate | 56.4 | 56.4 | 56.4 |
| Filler Type | V38/45 | Ka5 | Ka20 |
| Filler | 10.2 | 10.2 | 10.2 |
| 50/70 Bitumen | 6.0 | 6.0 | 6.0 |

Hydrated lime was added by using different kinds of mixed filler, to be compared to standard mineral filler (with Rigden air void class V38/45). Mixed filler is defined in EN 13043 as a blend of hydrated lime with limestone filler. Mixed filler categories are labelled Kax, where x is the hydrated lime content in the filler. Mixed fillers are widely used in Northern Europe, especially in the Netherlands, where the preferred way of adding lime to Porous Asphalt is by using a Ka25 filler. Here, Ka5 and Ka20 were used to obtain SMAs with respectively 0.5 and 2% lime.

Samples were lightly compacted by gyratory compactor to an average of 8.4% air voids. They were then tested for moisture resistance using the Indirect Tensile Strength Ratio (ITSR – EN 12697-12 method A) comparing the dry Indirect Tensile Strength (ITS) to the wet ITS after a conditioning of 3 days in a water bath at 40°C.
These results are shown Figure 2. Clearly, the presence of only 0.5% lime was not sufficient to significantly impact the ITSR of the SMA. However, the formula with 2% lime had an improved moisture resistance [12].

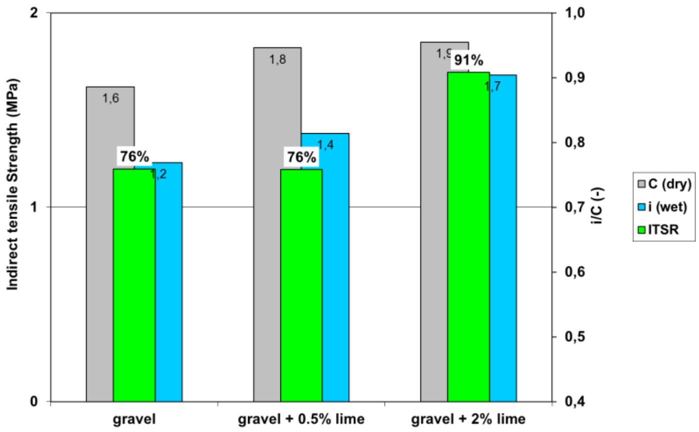


**Figure 2: Compressive strength of dry (C) / wet (i) specimens and retained resistance (ITSR) for a SMA made with with 0, 0.5 and 2% hydrated lime with river gravel under standard storage conditions (3 days in a 40°C water bath). Data from [12].**

This laboratory study was completed by a still-ongoing field experimentation [12]. Different SMA formulas were built on several highways in the country between March 2004 and August 2009. Sections are still being monitored. Although SMAs are known to be quite resistant to moisture damage, it was observed that the presence of hydrated lime through the use of Ka20 filler, had a positive effect on moisture damage, especially for mixtures having a high air void content. The authors therefore concluded that *"(...) the use of hydrated lime minimises possible risks occurring in the field with respect to durability issues of SMA mixtures"* [12].
These two examples made based on French ACs or Belgian SMAs demonstrate how hydrated lime can be used in order to improve the moisture resistance of different types of asphalt mixtures. The French study strongly suggests that hydrated lime could be beneficial in areas with severe winter conditions, where the use of de-icing salts can accelerate the degradation of the mixtures. The Belgian study shows that, even in the presence of high performance mixture such as SMA with modified bitumen, lime can still improve the moisture resistance.

## 3. AGEING RESISTANCE

Hydrated lime was early observed to decrease bitumen chemical aging. The first observations of the anti-ageing effect of hydrated lime on bituminous materials date back from the late 1960's in Utah, when C. V. Chachas and coworkers with the Utah State Department Highways observed that control specimens of bitumen recovered from hydrated lime treated asphalt mixtures were surprisingly softer than the reference materials [1]. Now, many laboratory and field studies have confirmed this effect and the mechanisms behind it have been clarified [6]. Still, most of the field evidence comes from the USA. Therefore, it is interesting to see if European case studies confirm these benefits.
A first set of information has been gathered by German researchers in a test section on L181 road in the city of Bräunlingen in the district of Schwarzwald-Baar in the Land of Baden-Würtemberg in South-East Germany (Figure 3 – [13]). This region experiences semi-continental climate (hot summer with frequent thunderstorms, relatively cold winter, large thermal amplitudes) with a somewhat mild and sunny version of it (the site is located in the sunniest part of Germany). Average yearly maximum temperature is close to 15.3°C (monthly minimum of 5.1°C in Jan. and maximum of 25.3°C in July – data for nearby Freiburg im Breisgau according to Wikipedia) and average yearly minimum temperature is close to 7.4°C (monthly minimum of -1.0°C in Jan. and maximum of 15.5°C in July). Precipitations average 862 mm per year.

A/ Reference AC 1 (Section A) B/ AC 1 with hydrated lime (Section D)

**Figure 3: View of A/ section A and B/ section D, respectively without and with hydrated lime on the L181 test after 12 years. From [13].**

**Table 3: Results of the monitoring of the AC 11 surf 70/100 on German L181 road in Bräunlingen built in July 2000 (from [13]). The data are given at construction and for 3 monitoring campaigns after 2 years (2002), 5 years (2005) and 11 years (2011). R&B of the recovered binder was measured, together with the void content in the mix and the lime content (see text).**

| | | Section A | Section B | Section C | Section D |
|---|---|---|---|---|---|
| | | AC 1 | AC 2 (reduced binder) | AC 2 with 2 % lime | AC 1 with 2 % lime |
| | Binder Type | 70/100 | 70/100 | 70/100 | 70/100 |
| | Binder content (%) | 6.2 | 5.9 | 5.8 | 6.0 |
| At construction | Air voids (%) | 5.6 | 4.0 | 3.6 | 3.5 |
| | R&B (°C) | 55.5 | 55.5 | 49.5 | 49.5 |
| After 2 years | Air voids (%) | 4.1 | 3.5 | 3.2 | 3.9 |
| | Hydrated lime (% in aggregate) | - | - | 2.0 | 2.0 |
| | R&B (°C) | 56.0 | 56.0 | 49.0 | 49.0 |
| After 5 years | Air voids (%) | 2.7 | 2.9 | 3.3 | 2.5 |
| | Hydrated lime (% in aggregate) | - | - | 2.2 | 2.2 |
| | R&B (°C) | 57.9 | 56.5 | 51.9 | 52.0 |
| After 11 years | Air voids (%) | 2.6 | 2.1 | 2.0 | 2.6 |
| | Hydrated lime (% in aggregate) | - | - | 2.3 | 2.2 |
| | R&B (°C) | 54.1 | 53.8 | 51.5 | 50.0 |
| | Rut depth (mm) | 2 | 2-3 | 2 | 0 |

The tested asphalt mixture consisted in AC 11 surf 50/70 according to current EN denomination (AB 0/11 according to then German specifications). The construction occurred in July 2000. Two mix formulas were used: One with the "correct" binder content (6.2% - AC1) as recommended from the formulation study, and a second one with voluntarily lowered binder content by 0.3%, with the idea to accelerate ageing. The jobsite has been monitored several times since 2000 [14] and the last testing has been performed in 2011, on 11 yrs old samples. At each monitoring step, cores were taken and composition was checked, including air voids, binder was extracted for ring and ball softening point measurement. Lime content could also be quantified using the German method [15,16]. The main results are summarized in Table 3.

Clearly, the R&B softening point of the sections with lime remained lower even after 11 years. Note that the last monitoring showed a surprising decrease in softening point as compared to previous ones, which remain to be explained. Still, this section showed that the impact of hydrated lime in these conditions was to lower the softening point from 2.3 to 7.0°C has compared to that of the untreated material. Interestingly, the lime content was found to be similar to the initial content with even after 11 years, showing that no carbonation had occurred.

Another similar monitoring has been organized in Poland. The test section that was monitored was built in 1999 on Zelazna street in the city of Kielce (Figure 4 – [17,18]). Kielce experiences continental climate with oceanic influence. This materializes by cool winters with frequent snowfall, and moderately warm and sunny summers, with abundant rainfall. Average yearly maximum temperature is close to 12.2°C (monthly minimum of 0.2°C in Jan. and maximum of 23.9°C in July – data from Wikipedia) and average yearly minimum temperature is close to 3.7°C (monthly minimum of -4.8°C in Feb. and maximum of 12.7°C in July). Precipitation averages 601 mm per year.

A/ Reference SMA

B/ SMA with 3 % lime

**Figure 4: View of the reference section (A) and the section with lime (B) on Zelazna street after 11 years. From [17].**

The section consisted in a 200-mm cold-recycled (with bituminous emulsion and cement) base course, 80 mm of binder course topped with 40 mm of SMA. All of these layers were built in 1999, on top of existing 150 to 240 mm of untreated aggregate. A polymer-modified SMA mixture with hydrated lime has been compared with a reference one having a fatty amine at 0.5% by weight of bitumen [17,18]. The SMA mixture contained 5.8% (based on mix) 50/70 bitumen modified with 4% SBS polymer (PMB). Hydrated lime was introduced in the form of a Ka30 mixed filler. Note that a complete formulation study was performed [17], which showed that there was an optimum in mix properties for this combination of polymer / hydrated lime content. The mixture composition is described in Table 4.

**Table 4: Mix design for the Polish SMA 13 (%weight based on total mix except when otherwise stated) used on Kielce Zelazna street. Data from [17].**

| Component | Reference SMA | SMA with 3 % lime |
|---|---|---|
| 0/4 limestone sand | 11.3 | 11.3 |
| 2/6 dolomitic agg. | 14.1 | 14.1 |
| 2/6 quartzite agg. | 9.4 | 9.4 |
| 6/12.8 quartzite agg. | 49.9 | 49.9 |
| Limestone filler | 9.4 | - |
| Ka30 | - | 9.4 |
| Liquid antistrip | 0.5% based on binder | - |
| PMB | 5.8 | 5.8 |
| Air voids | 3.5% vol. | 3.7% vol. |

After 12 years of pavement life, samples were taken in 2011 on both sections and characterized [17,18]. In general terms, both sections were performing quite well with no major damage. Still, the monitoring had shown that signs of stripping had appeared after 8 years on the reference section when they were only seen after 10 years on the lime-modified one. Similarly, some raveling was appearing on the reference section after 12 years when no such damage was yet observed on the lime-modified section.

The main results from the sample testing are reproduced in Table 5. Apart from binder characterization, the moisture resistance was evaluated by measured the retained resistance using both the ITSR test (EN 12697-12 method A) and the American AASHTO T283 (“Lottman test” – noted Tensile Strength Retained “TSR”) after 6 freeze-thaw cycles (Table 5).

**Table 5: Results of the monitoring of the Polish SMA 13 placed on Kielce Zelazna street in 1999. The data are given at construction and after 12 years (2011). Data from [17].**

| | | Reference SMA | SMA with 3 % lime |
|---|---|---|---|
| Initial | Pen. (1/10 mm) | 55 | 55 |
| | Fraass (°C) | -12 | -12 |
| After 12 years | Air voids (%) | 3.7 | 3.5 |
| | Pen. (1/10 mm) | 41 | 46 |
| | Fraass (°C) | -9 | -10 |
| | ITSR (%) | 92.0 | 94.5 |
| | TSR (-) | 0.83 | 0.87 |

All of these results tend to prove that hydrated lime slowed down the ageing of the bitumen in this case also, even if the differences remain within experimental error. This was further demonstrated by Fourier Transform Infra-Red spectroscopy [18], which showed a lower oxidation of the bitumen with lime (lower carbonyl and sulphoxide indices) together with a better preservation of the polymer (higher trans-butadiene index).
These two examples based on German ACs or Polish SMAs highlight the impact of hydrated lime on the ageing of asphalt mixtures. Depending on the details of the site (type of mixture including binder origin and content, climate...), the effect was seen to reach between 2 to 7°C difference in R&B softening point the German case, when the effect was less marked but still significant in the Polish case.

## 4. BINDER STIFFENING

It is well documented that hydrated lime has a higher stiffening effect on the bitumen than regular mineral filler [1,4-6]. Note that, for reasons that still need to be explained, this effect is only present at high temperature and disappears below room temperature. The practical consequence is that although the rutting resistance can be increased, the resistance to thermal cracking remains unchanged [1].
In terms of rutting resistance, and as a rule of thumb, the impact of substituting 2% (based on the mix) of the filler by hydrated lime in an asphalt mixture is pretty much like using a harder bitumen grade by one class. More precisely, an AC with 50/70 bitumen and 2% hydrated lime should have a similar rutting resistance to that of the same AC with 35/50 bitumen and only standard mineral filler (all other parameters being kept unchanged). Given the temperature dependency of the stiffening by hydrated lime, they will however behave differently on the low-temperature side and the 50/70 mix should remain more flexible and less brittle, even with lime in it, than the 35/50 mix.
This effect on the rutting resistance is illustrated in the following formulation study from Austria. The mixtures were compared in-situ on a test section in 2004 on road B62 in Deutschkreuz (Bundenland). The AC for base courses (BT 32 LK S in the Austrian denomination) were made with 70/100 bitumen and either standard mineral filler or mixed filler Ka30 (Table 6).

**Table 6: Mix design for the AC 32 base 70/100 of the Austrian study (%weight based on total mix). Data from [19].**

| Component | Reference AC 32 base | AC 32 base with 3.5 % lime |
|---|---|---|
| 0/2 Sand | 24.0 | 23.2 |
| 2/32 Aggregate | 64.6 | 65.5 |
| Filler Type | V38/45 | Ka30 |
| Filler | 7.2 | 6.8 |
| 70/100 Bitumen | 4.2 | 4.5 |

The monitoring incorporated a comparison of the rutting resistance of mixtures compacted from field specimens (Figure 5). The hydrated lime containing formula exhibited a lower rut depth after 30,000 load cycles at 60°C following Austrian standard RVS 11.065-IV, with an average of 10.7 % for the reference AC (3.6 % air voids) to be compared with 6.6 % for the AC with hydrated lime (5.5 % air voids). The in-situ behaviour confirmed the results [20,21].

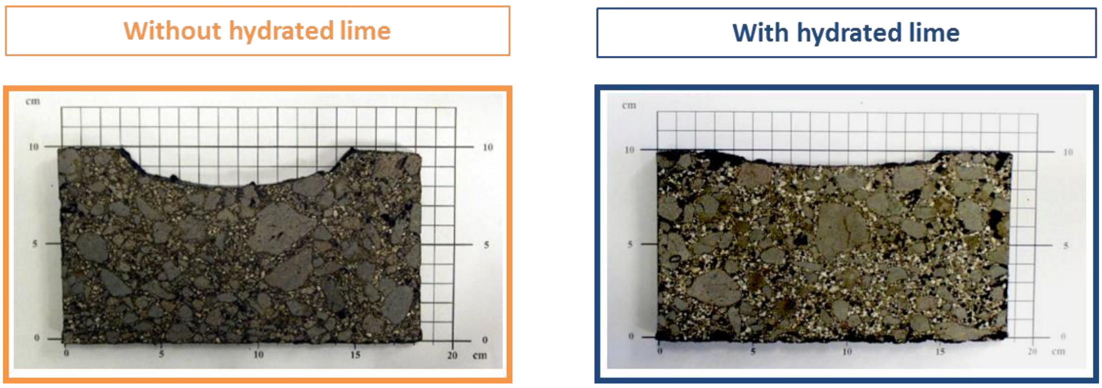


**Figure 5: Rut depth after 30,000 load cycles at 60°C in the wheel tracking (RVS 11.065-IV) on a AC 32 base 70/100 with (final rut depth 10.7%) or without 3.5% hydrated lime (Ka30 - final rut depth 6.6%). Reproduced from [20].**

If the benefits arising from the stiffening effect of hydrated lime are clearly exemplified in the previous example, it is worth detailing that the same effect can be used to limit binder drainage in open graded mixtures such as Porous Asphalt or SMA. The complete results from this study performed at the University of Pisa can be found in a companion paper [22]. Bitumen drainage from two types of mixtures (PA and SMA) with or without hydrated lime was quantified using the Schellenberg test (EN 12697-18). The mixtures were made out of basaltic aggregate and cellulose fibres were added when no lime was present (Table 7). The binder was either a SBS polymer-modified bitumen PMB (pen. 60 1/10 mm, R&B 75°C) for the PA or a 50/70 bitumen for SMA (Table 7).

**Table 7: Mix design for binder drainage study (%weight based on total mix). Data from [22].**

| Component | Reference PA | PA with 2.7% lime | Reference SMA | SMA with 3.5% lime |
|---|---|---|---|---|
| 0/4 Sand | 7.6 | 7.6 | 18.8 | 18.9 |
| 4/8 Aggregate | - | - | 17.9 | 17.9 |
| 8/12 Aggregate | 56.1 | 56.2 | 30.1 | 30.2 |
| 12/20 Aggregate | 24.7 | 24.8 | 18.8 | 18.9 |
| Filler | 6.7 | 4.0 | 8.5 | 5.1 |
| Cellulose fibres | 0.3 | - | 0.3 | - |
| Hydrated Lime | - | 2.7 | - | 3.4 |
| Binder Type | PMB | PMB | 50/70 | 50/70 |
| Bitumen | 4.7 | 4.7 | 5.6 | 5.7 |

The Schellenberg test consists in putting 1 kg of the mixture to be tested in a beaker and then for 1 hour in an oven at the maximum temperature to be experienced by the mixture during production. After this conditioning, the mixture is taken out of the beaker and the binder remaining on the beaker is weighted. Less than 0.3% remaining binder is generally considered to be the threshold for limited drainage.
The results for the PA and SMA with and without hydrated lime are shown on Figure 6. Clearly, the presence of hydrated lime allows avoiding binder drainage to the same extent as the reference formula where the draindown was limited thanks to the use of cellulosic fibres.

**A/ PA**
**4.7% PMB (based on mixture)**
**Test performed at 175°C**

**B/ SMA**
**5.7% 50/70 (based on mixture)**
**Test performed at 150°C**

Reference (fibres): 0.12%

Reference (fibres): 0.07%

With 2.7% lime (no fibres): 0.26%

With 3.5% lime (no fibres): 0.09%

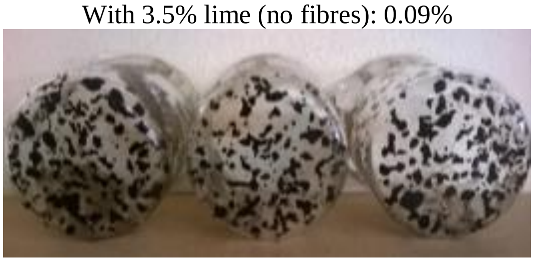

**Figure 6: Results of the Schellengerg binder drainage test (EN 12697-18) for the PA (A) and SMA (B) with fibres (reference on top) or with hydrated lime (bottom). The amount of retained binder in the beaker is given for all modalities, with <0.3 % considered as the threshold for acceptance. The pictures illustrate the beakers after the test (1 replicate for PA and 3 replicates for SMA). Reproduced from [22].**

These two examples, based on Austrian base ACs or Italian PAs or SMAs, illustrate two ways to use the binder stiffening property of hydrated lime in asphalt mixtures: One is to improve the rutting resistance and the other is to limit binder drainage in high bitumen content / high voids in mineral aggregate mixtures.

## 5. CONCLUSIONS AND FUTURE PERSPECTIVES

This paper tried to illustrate several ways to use the multifunctional properties of hydrated lime in asphalt mixture formulation, based on case studies from all over Europe. It shows that hydrated lime can be used successfully in all types of mixtures, whether dense / semi-dense or open-graded, base or surface courses, with neat bitumen or polymer-modified binder.
Hydrated lime is seen to improve the moisture resistance of mixtures, including in tough environment such as in the presence of de-icing salts. In parallel, hydrated lime slows down the ageing of the bitumen. Although limited European

field sections have demonstrated it, the German and Polish examples described herein clarify the potential impact. Finally, the binder stiffening effect is highlighted for improving the rutting resistance or avoiding binder drainage.

Even if each case study was focused on one main functionality, it was clear that the other functionalities could also be at play. For example, moisture-resistance and resistance to freeze-thaw cycles was improved in the Polish case in parallel to the reduced ageing, contributing to a longer durability.

In all cases, asphalt formulators must now have in mind that, besides binder and aggregate, there is an additional lever to be played with in order to fine-tune mixture properties: hydrated lime. It makes it a promising additive in the search of more sustainable and more durable asphalt pavements [23].

## 6. ACKNOWLEDGEMENTS

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