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# Increasing the durability of asphalt mixtures by hydrated lime addition: what evidence?


Given its impact on asphalt mixture durability, the French highway company *SANEF (Société des autoroutes du Nord et de l'Est de la France)* now requires the addition of 1.5% hydrated lime in the wearing courses of its network. Here, a A132 section near *Honfleur* in the *Calvados* department (Normandy)

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Hydrated lime has been known as an additive for asphalt mixtures from their very beginning. It experienced a strong interest during the 1970s in the USA, when moisture damage and frost became some of the most pressing pavement failure modes of the time.

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: hydrated lime reduces chemical ageing of the bitumen and stiffens the mastic more than usual mineral filler above room temperature, which can in turn improve the mechanical properties of the mix.

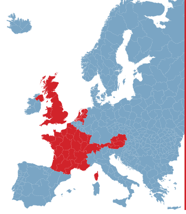
Given that all the above properties impact the durability of asphalt mixtures, the use of hydrated lime has a strong influence on asphalt mixture durability. This article reviews the corresponding evidence found in the literature.

The field experience from 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%.

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. The French experience suggest that hydrated lime modified asphalt mixtures have a longer durability by 2-3 years (20-25%). Similar observations led the Netherlands to specify hydrated lime in porous asphalt. As a result, hydrated lime is being increasingly used in asphalt mixtures in most European countries, in particular Austria, France, the Netherlands, the United Kingdom and Switzerland.

## Introduction

Hydrated lime has been known as an additive for asphalt mixtures from their very beginning [1 to 3]. 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 [4] and as a consequence, it is now specified in many States and it is estimated that 10% of the asphalt mixtures produced in the USA now hold hydrated lime [5].



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 [3, 6 to 9]. Hydrated lime is known to reduce chemical ageing of the bitumen [3, 6 to 8]. Furthermore, it stiffens the mastic more than normal mineral filler [3, 6 to 8], an effect that is only observed above 10°C [3]. 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 [3]. 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 temperature below 0°C, no negative effect on the thermal cracking resistance is reported in the literature [3, 6 to 8]. The mechanisms explaining why hydrated lime is so effective in modifying asphalt mixture are detailed elsewhere [10].

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. This article reviews the field evidence on this topic. It starts by a rapid description of the ways that hydrated lime can be added to the mixture. Then, the evidence coming from the USA is presented and finally, the European experience in terms of durability is described.

## Hydrated lime in asphalt mixtures in practice

### How to add hydrated lime to an asphalt mixture

There exist several ways to add hydrated lime in an asphalt plant. The hydrated lime content is generally between 1 and 2.5% of the dry aggregate, with a strong consensus around 1-1.5% (Table 1). Most mix formulation methods consider hydrated lime as a mineral filler. As a consequence, the filler content is reduced in the same amount as hydrated lime is added, so that total filler content is maintained constant.

The National Lime Association published a review of the methods currently used in the United States of America in order to put the hydrated lime into the mixes [11]. To these US methods, the mixed filler method in use in Europe must be added (Table 1). As a result, many studies exist that compare the several ways to add lime, with diverging conclusions as the best way [12 to 18]. Interestingly, all methods were found to be equally valid in order to benefit from the addition of hydrated lime [11, 19].

Therefore, the main factors affecting the selection of a given method are the choice of the plant manager and the local specifications.

**Pure hydrated lime at the asphalt plant**
Hydrated lime can be added to the asphalt plant by a dedicated silo with direct access to the mixer (Photo 1). In terms of capacity, it must be reminded that hydrated lime has a lower apparent density (0.35-0.8Mg/m$^3$) than mineral filler and that a minimum capacity must therefore be at least 60m$^3$ in order to unload a full truck. The silo has an aeration system with dehumidifier, with the air inlet system typically 1m above the cone of the silo. The silo is also equipped with a small filter baghouse on top [11].


**Photo 1**
Asphalt plant in Georgia with two silos: one for mineral filler and the other for hydrated lime (from [11])

In the case of a batch plant, the most common method consists in having the hydrated lime weighted in the same device that weighs the mineral filler. The installation therefore consists in connecting the hydrated lime silo to the existing system by means of a screw conveyor.

In the case of a continuous plant, the most common method consists in having a weigh pot dispensing hydrated lime through a rotary vane feeder. The hydrated lime is then injected into the drum through a screw conveyor. The entry point is typically 1m before the binder injection point [11]. This is a method in use in Europe (Austria, France, Germany, UK) and in Florida, Georgia, Montana and Texas (Table 1).

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# Increasing the durability of asphalt mixtures by hydrated lime addition: what evidence?

| Country/State | Hydrated Lime Content (%) | Pure Hydrated Lime | Ways to add hydrated lime | | | | |
|---|---|---|---|---|---|---|---|
| | | | Mixed Filler | Dry to Dry Aggregate | Dry to Wet Aggregate | Lime slurry to Aggregate | Marination |
| Europe | | | | | | | |
| Austria | 1.5-3.5 | X | | | | | |
| France | 1-1.5 | X | X | | | | |
| Germany | 1.5 - 3 | X | X | | | | |
| Netherlands | 2 | | X | | | | |
| Switzerland | 1.5 | X | | | | | |
| UK | 1-2 | X | | | | | |
| USA | | | | | | | |
| Arizona | 1 | | | | X | | |
| California | 0.7-1.2 | | | | | X | Required |
| Colorado | 1 | | | | X | X | Optional |
| Florida | | X | | | | X | |
| Georgia | 1 | X | | X | | | |
| Mississippi | 1 | | | | X | | |
| Montana | 1.4 | X | | | | | |
| Nevada | 1-2.5 | | | | X | | Required |
| New Mexico | | | | | X | | |
| Oregon | 1 | | | | X | | Optional |
| South Carolina | 1 | | | | X | | |
| South Dakota | | | | | X | | |
| Texas | 1-1.5 | X | | | X | X | |
| Utah | 1-1.5 | | | | | X | Optional |
| Wyoming | 1-1.5 | | | | X | | |

Table 1
Methods currently used to add hydrated lime to asphalt mixtures. Data for the USA are from [11]. Detailed data for Europe are given in Table 5. Here, the focus is on these European countries for which the use of hydrated lime is close to 1% or more (estimates in terms of percentage of HMA modified with hydrated lime compared to the total HMA production)

Note that initial implementation of this technology in continuous plants led to poor incorporation of hydrated lime into the mix because of losses as dust [2]. This could be solved by a proper modification of the hydrated lime feed, for example using donut-shaped baffles at the point of lime injection [2].

**Hydrated lime as a mixed filler**
Hydrated lime can be added to the asphalt plant using the same silo as the one already existing for mineral filler. In this case, hydrated lime must be mixed with the filler prior to the plant, and most companies supply mixed filler. Mixed filler is a standard product in Europe and several categories are described in the specifications for aggregates in asphalt mixtures (EN 13043 [29]). They are named "$Ka_{XX}$" where $_{XX}$ stands for numbers or text as summarized in Table 2.

Most European countries have experience with the mixed filler. Since the target hydrated lime content is 1-1.5% in all countries, the hydrated lime content inside the mix filler must be adjusted. As a result, the Netherlands specify hydrated lime in the form of $Ka_{25}$ with 25% hydrated lime for all their porous asphalts [20]. Germany has also a strong experience with $Ka_{25}$, but more categories can be found on the market [21].

| Category | Calcium hydroxide content (wt.%) |
|---|---|
| $Ka_{25}$ | ≥25 |
| $Ka_{20}$ | ≥20 |
| $Ka_{10}$ | ≥10 |
| $Ka_{declared}$ | <10 |
| $Ka_{NR}$ | No Requirement |

Table 2
Mixed filler categories as described in EN 13043 [29]

In both countries, the quantity of filler used in most of the surface mixes is high (5-10%) thanks to the use of washed sand. On the contrary, France uses mixed fillers with a higher quantity of hydrated lime. The trend there is to supply mixed filler with up to 75% hydrated lime, given the low quantities of added filler (typically 2%) as a consequence of using unwashed sand.

### Other forms to add hydrated lime

Other methods exist in order to add hydrated lime to an asphalt mixture. All of these additional methods are not currently used in Europe but are well developed in the USA (Table 1). Most of these methods use a pugmill in order to mix the hydrated lime with the aggregate (Photo 2). Still, it can also be sprayed directly on the aggregate on the belt conveyor, but this is not a preferred solution because of the loss of material by dusting [2].

The most common method consists in adding the hydrated lime in dry form (hence the need for a dedicated silo) to the wet aggregate using a pugmill (Photo 2). Still, some Georgia plants prefer to treat the dry aggregate (Table 1). Also, other States like California or Utah specify the use of a lime slurry instead of dry hydrated lime. This necessitates the presence of a lime slurry installation. The lime slurry method is also used in some plants in Colorado, Florida and Texas (Table 1).


Photo 2
Pugmill used to mix hydrated lime with the wet aggregate in South Carolina (from [11])

Finally, some States also specify a marination period of typically 24-48 hours. The aggregate can then be treated and stockpiled for marination directly in the quarry and the treated marinated aggregate can then be processed at the asphalt plant [11].

The marination process is thought to allow for a better treatment of clayey aggregates. Also, the quality control is simplified because the hydrated lime content can be measured directly on the stockpiled material.

The marination period must not be extended for too long, because of a risk of hydrated lime recarbonation. Therefore, some States specify a maximum marination time. For example, Nevada says no more than 45 days [11]. Still, it was shown that recarbonation even after 6 months is only present in the top 8cm of the stockpile [8], which would be of limited consequence for stockpiles higher than 2 meters.

## Observed increase in durability in the USA

The use of hydrated lime in asphalt mixtures has become widespread in the USA. As already mentioned in the introduction, we estimate that 10% of the asphalt mixtures manufactured in the USA now hold hydrated lime. However, the situation is not homogeneous and Figure 1 shows the repartition on a State by State basis. Interestingly, States experiencing tough climates, like those in the Rocky Mountains (severe winter) or those on the Gulf of Mexico (high humidity combined with high temperature), are favouring the use of hydrated lime. >>>

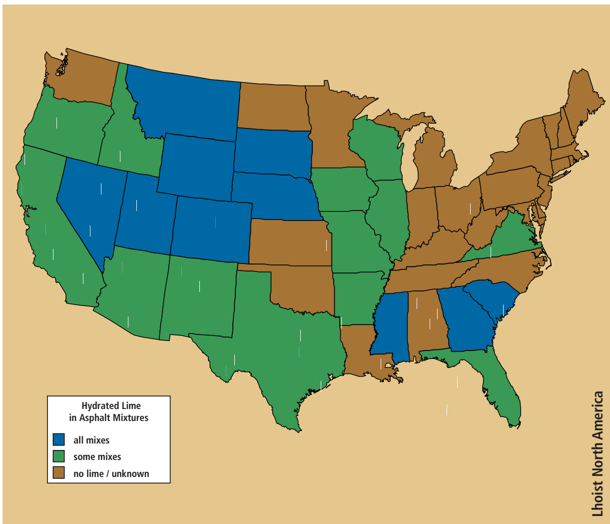


Figure 1
Current use of hydrated lime in the USA (courtesy of E. Berger)

# Increasing the durability of asphalt mixtures by hydrated lime addition: what evidence?

Reasons why those States now require hydrated lime were made clear in the 1991 survey of the existing additives used for treating moisture damage [4]: State agencies reported that hydrated lime was the most effective additive used so far (Figure 2). Moreover, no agency reported that hydrated lime was only slightly effective, whereas all other additives were considered so by some agencies.

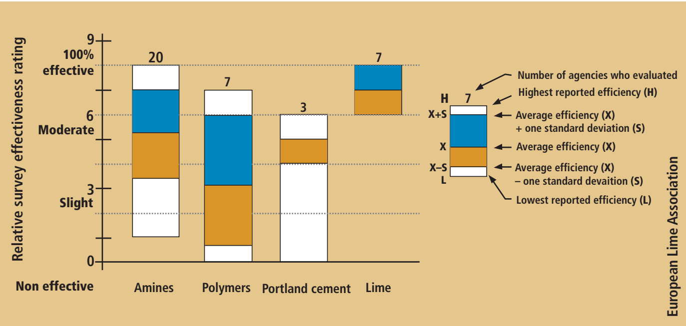


**Figure 2**
Comparison of the effectiveness of several additives in order to treat moisture damage as evaluated by North American State agencies experience (adapted from [4])

In a more recent survey performed in 2003, the State agencies reported that the first reason why they use hydrated lime is because of moisture damage (Table 3 - [5]). Given the more than 30 years of experience with hydrated lime in the USA, its effect on pavement durability is well documented.

In the National Lime Association survey of 2003, precise numbers on the changes in asphalt mixtures durability thanks to the treatment by hydrated lime were given [5]. The survey was performed by sending a questionnaire to all the agencies that are experienced in the use of hydrated lime. The full results are reproduced in Table 4.

From these data, it can be seen that, according to the North American State Agencies, the life expectancy for all types of roads is increased by 2 to 10 years when hydrated lime is added. Given that the life expectancy of untreated roads ranges from 5 to 20 years, the relative improvement goes from 20 up to 50% higher durability.

## Observed increase in durability in Europe

The use of hydrated lime in asphalt mixtures is growing in Europe. Table 5 summarizes this current situation. All data were gathered by the European Lime Association (EuLA) Asphalt task force.

Even if the situation in Europe is not as fully documented as in the USA, the local experiences show that the beneficial effect of hydrated lime allows for an increased durability of typically 20-25% in terms of pavement life expectancy.

| Agency | Resist Stripping | Improve Aging Resistance | Stiffen Binder | Improve Fracture Toughness | Alter Properties of Fines |
|---|---|---|---|---|---|
| Arizona | 1 | 3 | 2 | 3 | 2 |
| California | 1 | 2 | 3 | 3 | 3 |
| Colorado | 1 | 3 | 3 | 3 | 1 (when appropriate) |
| FHWA | 1 | 2 | 3 | 2 | 3 |
| Georgia | 1 | 3 | 3 | 3 | 3 |
| Mississippi | 1 | 1 | 2 | - | 3 |
| Nevada | 1 | 3 | 3 | 2 | 1 |
| Oregon | 1 | 2 | 3 | 3 | 3 |
| South Carolina | 1 | 2 | 2 | 2 | 2 |
| Texas | 1 | 3 | 2 | 3 | 2 |
| Utah | 1 | 2 | 2 | 2 | 2 |
| Level of importance: | 1: Very important | | | | |
| | 2: Moderately important | | | | |
| | 3: Less important | | | | |

European Lime Association

**Table 3**
Reasons why to use hydrated lime as evaluated by USA State agencies experience (adapted from [5])

| Agency | Lime Treated | | | Non-Lime Treated | | |
|---|---|---|---|---|---|---|
| | 10% | Average | 90% | 10% | Average | 90% |
| **Interstate Highways** | | | | | | |
| Arizona | 13 | 15 | 17 | 10 | 12 | 14 |
| California | 8 | 10 | 12 | 6 | 8 | 10 |
| Colorado | 8 | 10 | 12 | 6 | 8 | 10 |
| Georgia | 7 | 10 | 15 | | N/A | |
| Mississippi | 7 | 10 | 15 | | N/A | |
| Nevada* | 7 | 8 | 9 | 3 | 4 | 7 |
| Oregon | 10 | 15 | 20 | 8 | 12 | 15 |
| South Carolina | 10 | 12 | 15 | | N/A | |
| Texas | 8 | 12 | 15 | 7 | 10 | 12 |
| Utah | 15 | 20 | 25 | 7 | 10 | 15 |
| **State and U.S. Highways** | | | | | | |
| Arizona | 18 | 20 | 22 | 15 | 17 | 20 |
| California | 8 | 10 | 12 | 6 | 8 | 10 |
| Colorado* | 8 | 10 | 12 | | 8 | |
| FHWA | 15 | 20 | 25 | | N/A | |
| Georgia | 8 | 10 | 14 | | N/A | |
| Mississippi | 12 | 15 | 17 | | N/A | |
| Nevada | 10 | 12 | 14 | 6 | 8 | 10 |
| Oregon | 15 | 17 | 20 | 8 | 12 | 15 |
| South Carolina | 8 | 10 | 12 | | N/A | |
| Texas | 10 | 12 | 15 | 8 | 10 | 12 |
| Utah | 15 | 20 | 25 | 7 | 10 | 15 |
| **Low Volume Roads** | | | | | | |
| Arizona | 20 | 25 | 30 | 15 | 20 | 25 |
| California | | N/A | | | N/A | |
| Colorado* | 10 | 12 | 15 | 8 | 10 | 12 |
| FHWA | 15 | 20 | 25 | | N/A | |
| Georgia | 8 | 10 | 15 | 8 | 10 | 15 |
| Mississippi | 12 | 15 | 17 | | N/A | |
| Nevada | 18 | 20 | 22 | 12 | 15 | 18 |
| Oregon | 15 | 20 | 25 | 7 | 10 | 15 |
| South Carolina | 10 | 15 | 20 | | N/A | |
| Texas | 8 | 12 | 15 | 7 | 10 | 15 |
| Utah | 7 | 10 | 15 | 3 | 5 | 7 |

* pavement preservation, N/A = not applicable

EuLA

**Table 4**
Life expectancy of hydrated lime treated and untreated mixes in the USA (adapted from [5])

The French motorway network *SANEF* commented that hydrated lime increases the durability of its wearing courses by 20-25% [27]. For example, one the very first application of porous asphalt in France was in 1984 on the A1 motorway from Paris to Lille. This highway is part of the *SANEF* network, one of the busiest highway in France, then with 35,000 vehicles per day with 27% heavy trucks. 10km of porous asphalt between *Ressons* and *Compiègne* (Lille-Paris direction) with a hydrated lime and crumb-rubber modified asphalt mixture [22, 23] were laid down and lasted over 16 years. A more recent application, in 1992, of porous asphalt with polymer-modified bitumen and hydrated lime >>>

on the A4 motorway in *Reims* gave a similar duration of 17 years. Experience with untreated porous asphalt gave expectancies of order 12 years, validating the increased durability.

The Danish experience also reports increases in durability of order of 20% for hydrated lime treated mixtures [24].

The Netherlands specify hydrated lime in their porous asphalts [20, 25]. Porous asphalts there are made exclusively out of unmodified 70/100 penetration grade bitumen and covers 70% of the highway network [26]. The current formulations give a life expectancy of 11 years [26]. Although no reference without hydrated lime allows for a direct evaluation of the observed increase in durability, the lack of hydrated lime is known to be one of the major reasons for premature failure [26].

In addition, it is also interesting to note that the *Fédération Internationale de l'Automobile (FIA)* specifies hydrated lime in the wearing courses of the race tracks (Table 6).

As a consequence, the observed durability increase in Europe agrees with the data published in the USA. From the extensive field experience worldwide, the road managers report that hydrated lime increases the durability of asphalt mixtures by at least 20-25%.

| Country | Level of experience | Start | [Lime treated HMA] vs [total HMA] (estimate %) | % hydrate in HMA | Form | Objective | Applications |
|---|---|---|---|---|---|---|---|
| Austria | Voluntary | 2003 | 1 | 1.5 to 3.5 | Pure | Stripping, rutting | AC, SMA, PA |
| Belgium | From compulsory to voluntary | 80's | < 1 | 1.5 | Mixed filler | Stripping | SMA, PA (asphalt rubber) |
| Czech Republic | Tests | 1996 | < 1 | 1.5 | Pure | Stripping, rutting | AC, PA (asphalt rubber) |
| Denmark | Voluntary | Mid 90's | < 1 | 1 to 1.5 | Pure | Stripping | AC |
| Finland | Voluntary | ? | < 1 | 1 to 2 | Pure or MF | Stripping, aging, other | AC, SMA, CMA |
| France | Voluntary | ? (> 1945) | 1 | 1 to 1.5 | Pure or MF | Stripping, aging, other | AC, CMA, PA, PA (asphalt rubber), *BBTM* |
| Germany | Voluntary | 2000 | < 1 | 1 to 3 | Pure or MF | Stripping, aging | AC, SMA |
| Hungary | Tests | 2009 | < 1 | 2 | To be defined | Stripping, rutting | AC |
| Ireland | Voluntary | 2001 | < 1 | 2 | Pure | Stripping, rutting | PA |
| Italy | Voluntary | Mid 90's | < 1 | 1 to 2 | MF | Stripping | SMA, PA |
| The Netherlands | Compulsory | Mid 90's | 7 | 2 | MF | Stripping, Aging, Durability | PA |
| Poland | Voluntary | 1998 | < 1 | 1 to 3 | MF | Stripping | AC |
| Portugal | Voluntary | Beginning 2000's | < 1 | 1 to 2 | Pure | Stripping | PA (asphalt rubber) |
| Romania | Tests | 2007 | < 1 | 2 | MF | Stripping, rutting | AC, SMA |
| Slovakia | Tests | 2009 | < 1 | 2 | Pure or MF | Stripping | |
| Spain | Voluntary | 2004 | < 1 | 1 to 2 | Pure | Stripping | SMA |
| Sweden | Voluntary/ compulsory | 1998 | < 1 | 1 | Pure | Stripping, aging | AC |
| Switzerland | Preferred | 2006 | 1 | 1.5 | Pure | Stripping, aging, durability | PA, AC, SMA, |
| UK | Voluntary | Early 00's | 1 | 1 to 2 | Pure | Stripping | AC |

AC: Asphalt Concrete ; SMA: Stone Mastic Asphalt; PA: Porous Asphalt; CMA: Cold Mix Asphalt; BBTM: Very Thin Asphalt Layer; MF: Mixed Filler

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Note that the values for the percentage of HMA modified with hydrated lime in the total HMA production is a rough estimate used to quantify the level of "lime awareness" in each country (in blue, more than 5% of the HMA production is modified with hydrated lime and in grey, about 1%)

**Table 5**
Current use of hydrated lime in asphalt mixtures in Europe (estimates from EuLA Asphalt task force)

| Country | Race Track | Year Built | Binder |
|---|---|---|---|
| Brasil | Rio de Janeiro | 1999 | PMB |
| Portugal | Estoril | 2001 | |
| Italy | Fiorano | 2002 | |
| Bahrein | Manama | 2003/04 | |
| China | Shanghai | 2004 | |
| Spain | Barcelona | 2004 | |
| Turkey | Istanbul | 2005 | 50/70 + TE |

EuLA

Table 6
Race tracks built with hydrated lime modified mixtures.
The last column states the type of binder used (PMB = Polymer-modified bitumen, TE = Trinidad Epure, a natural hard asphalt)

## Conclusions

Over the past 40 years, hydrated lime has become one key additive for asphalt mixtures, with a strong presence in the USA and a growing use in Europe [3]. It is now seen as a multifunctional additive that increases the durability of asphalt mixes through its improvement of [3, 6 to 9]:

- the resistance to moisture damage and frost,
- the resistance to chemical ageing,
- the mechanical properties, in particular modulus, strength, rutting resistance, fatigue and thermal cracking.

Hydrated lime is typically added at a rate of 1-2% by weight of asphalt mixture. Ways to add it can be:

- In dry form directly in the drum/mixer with a dedicated silo, as seen in the USA and in Europe;
- As a mixed filler, that is blended with typically limestone filler, using the existing silo in the asphalt plant, as seen in Europe only;
- On the aggregate before the dryer, with or without marination, in dry form or as a slurry, a method widespread in the USA but not used in Europe.

The experience of public and private road managers in North America and Europe converge to the fact that hydrated lime increases the durability of asphalt mixtures by more or less 25%. As a result, hydrated lime is being increasingly used in asphalt mixtures in most European countries, in particular Austria, France, the Netherlands, the United Kingdom and Switzerland. ■


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