USE OF HYDRATED LIME IN WARM-MIX ASPHALT

Didier Lesueur[1], Jesus Lopez Gonzalez[2], Aurelio Ruiz Rubio[2]
[1]Lhoist R&D, Nivelles, Belgium
[2]CIESM / Intevia, Madrid, Spain

ABSTRACT

Hydrated lime is a known additive for Hot Mix Asphalt (HMA) but its use in Warm Mix Asphalts (WMA) is not well described.

In this paper, the use of hydrated lime in WMA has been reviewed. Most technologies have been shown to be improved by hydrated lime. WMA technologies making use of surfactants need a careful mix design study in order to assess their compatibility with lime. When surfactant is an adhesion promoter, substitution by hydrated lime would probably be equally efficient. When surfactant is a lubricant, a risk of surfactant overconsumption exists due to adsorption on the lime particles.

A new way to use hydrated lime for WMA is presented: wet hydrated lime (WHL) as a new foaming agent and compacting aid. Two products with 20% moisture were evaluated at additive contents ranging from 0.3 to 1%.

The testing was done on Asphalt Concrete made with river gravel or porphyric aggregate. They were manufactured at 162°C and compacted at 150°C (HMA) or at 132°C and 120°C respectively (WMA).

The moisture resistance of all mixtures was evaluated using NLT 162 (ASTM D1075) with 24 hours conditioning at 60°C. The addition of 1% WHL was seen to increase the retained resistance of WMA formulas to the level of the reference HMA, sometimes even surpassing its performance.

As a conclusion, WHL can be used as a WMA additive. Apart from the foaming and compacting-aid role, it also brings the other functionalities of hydrated lime: improved adhesion, reduced aging and improved mechanical properties.

Keywords: warm-mix asphalt, hydrated lime, moisture damage

1 INTRODUCTION

Hydrated lime has been known as an additive for asphalt mixtures since their inception [1,2,3]. The use of hydrated lime became very popular in the USA in the 1970s, 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 frequent pavement failure modes of the time. Hydrated lime was observed to be the most effective additive to prevent those failures [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 contain hydrated lime [5].

Given its extensive use in the past 40 years in the USA, hydrated lime has been proven to be more than a moisture damage additive [3,6,7,8,9]. Hydrated lime is known to reduce chemical ageing of the bitumen [3,6,7,8]. Furthermore, it stiffens the mastic more than normal mineral filler [3,6,7,8], an effect only observed above room temperature [3], that has an impact on the mechanical properties of the asphalt mixture.

Given that all of the above mixture properties impact the durability of asphalt mixtures, the use of hydrated lime has a strong influence on the durability of asphalt mixtures:

- North American State Agencies estimate that hydrated lime at 1-1.5% in the mixture increases the durability of asphalt mixtures by 2 to 10 years, that is by 20 to 50% [5],
- The French Northern motorway company, Sanef, currently specifies hydrated lime in the wearing courses of its network, because they observed that hydrated lime modified asphalt mixtures have a 20-25% longer durability [10].
- Similar observations led the Netherlands to specify hydrated lime in porous asphalt [11], a type of mix that now covers 70% 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, the United Kingdom and Switzerland.

Still, the experience with hydrated lime is mostly limited to Hot Mix Asphalt (HMA). Now, with the growing use of Warm Mixes (WMA) [12,13,14], it is interesting to review the use of hydrated lime in combination with warm mix additives and/or processes. In this paper, WMA is used as a generic name for all technologies allowing the manufacturing of asphalt mixtures at temperatures 30°C to 60°C below the usual temperature. In other words, what some people call “semi-warm mixes” or “half-warm mixes” are also included in this definition of WMA.

As a general comment, the effect of hydrated lime on WMA should similar to that found on HMA. In fact, hydrated lime is known to modify asphalt mixtures essentially through the following mechanisms [15]:

- Bringing calcium ions to the aggregate surface, from which bitumen/aggregate adhesion is improved,
- Neutralizing the acids of the bitumen, from which (i) bitumen/aggregate adhesion is also improved and (ii) bitumen chemical ageing is slowed down,
- Stiffening the binder due to a higher porosity than that of “normal” mineral filler.

In principle, all of these mechanisms are also beneficial to WMA and it is therefore not surprising that most WMA technologies, such as foamed bitumen, zeolites or waxes, have already been shown to be improved when hydrated lime is added (Table 1).

Still, hydrated lime has a large surface area (typically $15 m^2/g$ [16]), that is 2 to 10 times larger than the mineral filler already present in the mix [3]. As a consequence, when surfactant is used in a WMA technology, there is a risk of surfactant adsorption on the hydrated lime particles. Depending on the role of the surfactant, two options are then available to the designer:

- If the surfactant is only used as an adhesion promoter, then hydrated lime could be successfully substituted for the surfactant [17]. In addition, hydrated lime would bring additional benefits such as reduced aged-hardening and improved mechanical properties.
- If the surfactant is used as a lubricant, then an additional amount would probably be needed in order to compensate for the adsorption on the hydrated lime particles. Here, it would be wise for the designer to validate at the lab scale whether the surfactant dosage has to be adapted in the presence of hydrated lime (Table 1).

As a result, a summary of the compatibility of existing WMA technologies with hydrated lime is proposed (Table 1). As can be seen, most WMA technologies have already been shown to be compatible with hydrated lime.

Table 1: Compatibility of hydrated lime (HL) with existing WMA technologies.

Type of WMA Technology	Name of WMA Process (Supplier)	Typical Temperature Reduction	Compatibility with Hydrated Lime	Comments
Foamed bitumen	Double Barrel® Green (Astec), Ultrafoam® (Gencor), Aquablack® (Maxam), LEAB® (BAM)	30°C	Yes	HL recommended – Already used in combination with HL on a daily basis in the USA – [18,19,20]
Double coating incl. foamed bitumen	WAM-Foam® (Kolo Veidekke / Shell), Enrobé 3E DM (Colas)	60°C	Yes	HL recommended
Wet aggregate	LEA, EBT, EBE (LEA-CO / Eiffage TP / Fairco)	60°C	Yes	HL recommended – adhesion promoter not necessary if HL is used
Emulsion	Evotherm® ET, Evotherm® DAT (MeadWestVaco / Eurovia)	60°C	To be checked	Risk of surfactant overdosing due to adsorption on the lime particles – Compatibility with HL must be checked in the mix design
Waxes	Sasobit® (Sasol), Asphaltan-B (Remonta), Licomont® BS 100 (Clariant), SonneWarmix® (Sonneborn), Enrobé 3E LT (Colas)	30°C	Yes	HL recommended - see [14,21]
Zeolites	Aspha-Min® (Aspha-Min), Advera® WMA (PQ), Asfalite (Ankerpoort)	30°C	Yes	HL recommended - see [14,21,22,23,24]
Surfactants	Evotherm® 3G (MeadWestVaco), Cecabase® RT (Ceca), CWM (Colas), Rediset® WMX (AkzoNobel)	30°C	To be checked	Risk of surfactant overdosing due to adsorption on the lime particles – Compatibility with HL must be checked in the mix design

Given this background, it was decided to focus on a different way of benefitting from hydrated lime in a WMA. As a matter of fact, hydrated lime is a porous material that can therefore be used as a water carrier and compacting aid. As can be seen in Figure 1, the kinetics of water release at 130°C of a wet hydrated lime is quite slow and could therefore be used as a foaming agent in WMA technologies. Once the water has been released, the known benefits of hydrated lime will then be at work, including the adhesion promoter effect. Therefore, this paper shows the possibility of using hydrated lime as both a water carrier and a compacting aid in WMA technology.

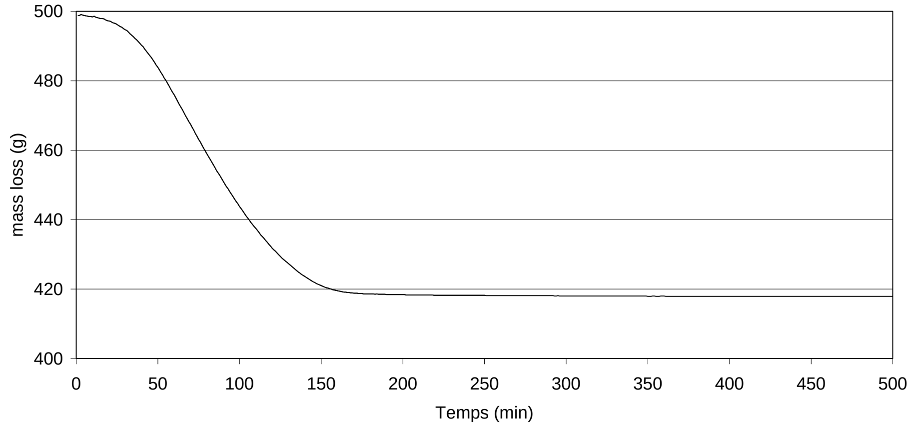

Figure 1: Mass loss at 130°C of a standard wet hydrated lime with initially 20% water.

2 EXPERIMENTAL

2.1 Materials

The testing was done with two reference hot mix asphalt mixtures made out of two different aggregate sources. The first mix, called M1 in the rest of the paper, was an AC16 Surf 50/70 (according to EN 13108-1) using the composition described in Table 2. The second mix, called M2 in the rest of the paper, was an AC22 Surf 50/70 (according to EN 13108-1) using the composition described in Table 3. All mixtures were made first with a hot mix as a reference (called HMA in the rest of the paper) and then with a series of warm formulas (called WMA). The WMA formulas differed by the type and content of used additive.

The same 50/70 bitumen from the Repsol Puertollano refinery was used for all mixtures.

Mixtures M1 were obtained using 24% of a 0/6 sand, 36% of a 6/12 aggregate and 16% of 12/18 aggregate coming from the crushing of the same siliceous river gravel from the Madrid region (Jarama quarry) together with 24% of a 0/6 limestone sand. All M1 mixtures, either in the hot mix or in the warm mix version, were made with 4.75% bitumen (Table 2).

Mixtures M2 were obtained using 60% of a 0/6 sand, 10% of a 6/12 aggregate, 10% of 12/20 and 20% of a 20/25 porphyric aggregate coming from the Cuadrado quarry in the Avila region. All M2 mixtures, either in the hot mix or in the warm mix version, were made with 4.8% bitumen (Table 3).

Table 2: Composition of the tested asphalt mixtures made with river gravel (M1) and standard (WHL1) or high surface area (WHL2) wet hydrated lime.

AGGREGATE GRADING		HMA M1	WMA M1 0.3%WHL1	WMA M1 0.5%WHL1	WMA M1 1.0%WHL1	WMA M1 0.3%WHL2	WMA M1 1.0%WHL2
% passing	22 mm	100	100	100	100	100	100
	16 mm	94	94	94	94	94	94
	8 mm	70	70	70	70	70	70
	4 mm	41	41	41	41	41	41
	2 mm	27	27	27	27	27	27
	500 µm	15	15	15	15	15	15
	250 µm	12	12	12	12	12	12
	63 µm	5.4	5.4	5.4	5.4	5.4	5.4
Type of wet hydrated lime		-	WHL1	WHL1	WHL1	WHL2	WHL2
Content of wet hydrated lime (%)		-	0.3	0.5	1.0	0.3	1.0
Binder content (% based on mixture)		4.53	4.53	4.53	4.53	4.53	4.53
Air voids (%)		9.2	9.4	9.7	9.5	9.6	8.3
Mixing Temperature (°C)		162	132	132	132	132	132
Compaction Temperature (°C)		150	120	120	120	120	120

Table 3: Composition of the tested asphalt mixtures made with porphyric aggregate (M2) and standard wet hydrated lime (WHL1).

AGGREGATE GRADING		HMA M2	WMA M2 0.3%WHL1	WMA M2 1.0%WHL1
% passing	32 mm	100	100	100
	22 mm	96	96	96
	16 mm	80	80	80
	8 mm	65	65	65
	2 mm	37	37	37
	500 µm	19	19	19
	250 µm	14	14	14
	63 µm	6.0	6.0	6.0
Type of wet hydrated lime		-	WHL1	WHL1
Content of wet hydrated lime (%)		-	0.3	1.0
Binder content (% based on mixture)		4.58	4.58	4.58
Air voids (%)		7.7	8.4	8.2

Mixing Temperature (°C)	162	132	132
Compaction Temperature (°C)	150	120	120

As a WMA additive, wet hydrated lime was prepared using two different ways. The first way consisted in taking a sample of standard hydrated lime for building and construction (CL 90 S according to EN 459-1) with the trade name Alpha 63 from the Jemelle Lhoist plant in Belgium. This starting material comes in a dry form with a moisture content close to 0 %. 20 wt.% of water was gently added to the hydrated lime under mild agitation in a Hobard mixer. The recovered wet hydrated lime is called WHL1 in this paper.

The second way consisted in taking a sample of high surface area hydrated lime with the trade name Proviacal® SP from the Hermalle Lhoist plant in Belgium. It had a surface area close to 45 m^2/g, as measured by the Brunauer-Emmett-Teller (BET) method using nitrogen adsorption, which is three times the value for standard hydrated lime [16]. This special hydrated lime is found to have interesting applications in other fields, for example as a binder for grouting mortars in tunnel engineering [25]. In part of the manufacturing process of this special product, the material can be taken in a wet form with a moisture content of 20 %. The corresponding wet hydrated lime is called WHL2 in the paper.

2.2 Methods

The HMA were manufactured at 162°C and compacted by static compaction at 150°C. The WMA were manufactured at 132°C and compacted by static compaction at 120°C. Air voids for the different mixtures are given in Table 2. They correspond to the average value obtained on the specimens for the immersion-compression test.

Workability was manually assessed during sample preparation.

The testing for HMA and WMA was mainly focused on moisture damage. This was done using the immersion-compression test (NLT 162 - ASTM D1075). The compressive strength of 101.6 x 101.6 mm^2 specimen was assessed in dry conditions and after a conditioning of 24hrs in a water bath at 60°C. The ratio of the wet compressive strength divided by the dry one is called the retained resistance (expressed in %).

3 RESULTS AND DISCUSSION

3.1 Use of wet standard hydrated lime

The results of the immersion-compression test for standard wet hydrated lime (WHL1) in mixtures made with river gravel (M1) are shown in Figure 2.

As can be seen from these data, the presence of a small amount of WHL1, namely 0.3%, in WMA M1 yielded a lower retained resistance than with the hot mix reference HMA M1 (Figure 2). In parallel, workability was deemed to be correct for this WMA, i.e. very similar to that of the HMA reference, as confirmed by their similar final densities (Table 2). This confirmed the potential of wet hydrated lime to be used as a foaming agent and compacting aid. However, the presence of water in the mix (0.06% initially coming from WHL1) clearly had a detrimental effect on adhesion and the low final hydrated lime content (0.24%) was not enough to correct this.

Increasing the amount of WHL1 to 0.5 and 1% allowed for a better compensation for the loss of adhesion (Figure 2). In parallel, these job mix formulaes also showed a good workability, confirming that higher amounts of WHL1 also had the effects of foaming and aiding compaction. Interestingly, and although higher amounts of water were present in the mixes (0.1% and 0.2% respectively for 0.5 and 1.0% WHL1), the higher the wet hydrated lime content, the higher the retained resistance (Figure 2). This was not at all surprising because the amount of hydrated lime in the final mixture also increased to 0.4% and 0.8% respectively, hence a stronger effect on adhesion. In other words, the beneficial effect of hydrated lime on adhesion was strong enough to overpass the detrimental effect of adding more water.

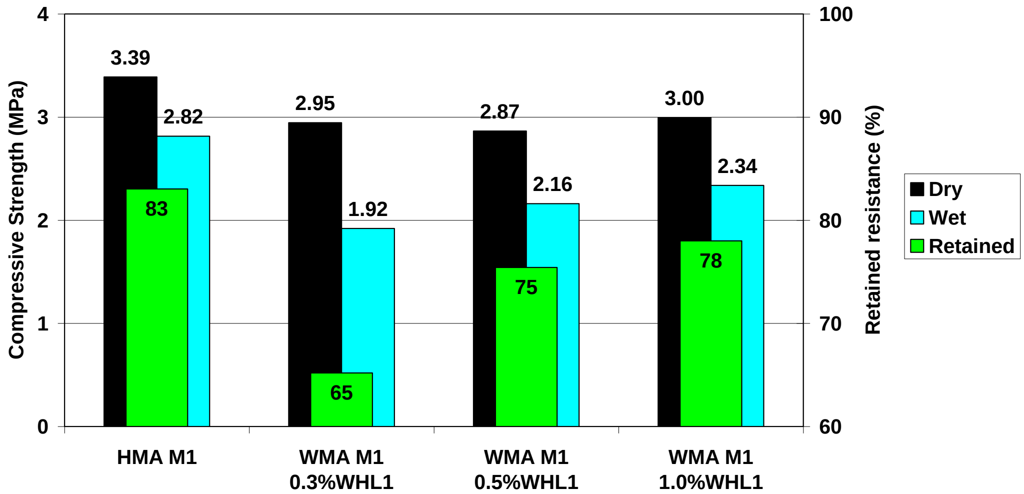

Figure 2: Dry and wet compressive strengths and retained resistance for HMA and WMA made of river gravel (M1 mixes). The WMA were made by using increasing amounts (0.3 to 1.0% based on aggregate) together with standard wet hydrated lime (WHL1) with 20% water.

The results were repeated with another aggregate source and mixture type using again wet hydrated lime (WHL1) but this time in mixtures made with porphyric aggregate (M2). The corresponding immersion-compression results are shown in Figure 3.

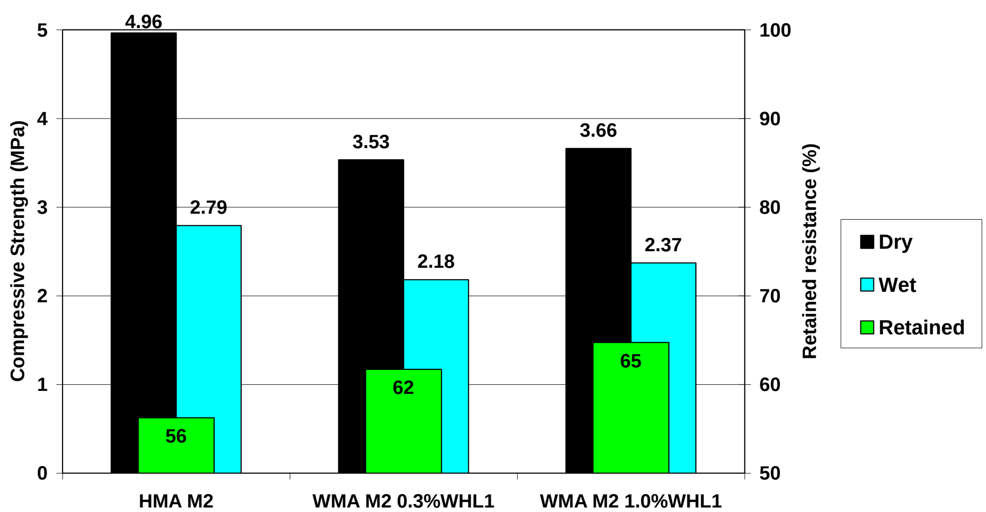

Figure 3: Dry and wet compressive strengths and retained resistance for HMA and WMA made of porphyric aggregate (M2 mixes). The WMA were made by using increasing amounts (0.3 to 1.0%) together with standard wet hydrated lime (WHL1) with 20% water.

As can be seen from these data, the presence of a small amount of WHL1, namely 0.3%, in WMA M2 yielded a better retained resistance than with the hot mix reference HMA M2 (Figure 3). In parallel, workability was deemed to be correct for WMA M2 with 0.3% WHL1, which is similar to the HMA reference, as confirmed by their similar final densities. This confirmed again the potential of wet hydrated lime to be used as a foaming agent and compacting aid. Still, and with this aggregate source, the presence of water in the mix (0.06% initially coming from WHL1) was not as detrimental because the presence of low final hydrated lime content (0.24%) was already enough to not only correct the detrimental effect of water, but also to correct some of the weak adhesion obtained for the reference HMA.

Increasing the amount of WHL1 to 1% allowed to even better compensate for the weak initial adhesion of HMA (Figure 3). In parallel, the 1% recipe also showed a good workability, confirming that higher amounts of WHL1 also had the effect of foaming and aiding compaction. Therefore, this second set of asphalt mixtures showed that in some cases, the beneficial effect of hydrated lime on adhesion could be strong enough not only to overpass the detrimental effect of adding more water but also to improve a weak initial adhesion in the HMA.

As a conclusion, these two sets of data with asphalt mixtures made with 2 different aggregate origins, showed that wet hydrated lime can be favourably used as a foaming agent and compacting aid in order to manufacture a new class of warm mixes. The advantage of using hydrated lime as water carrier is that its beneficial effect on adhesion can be used to counteract the detrimental effect of adding water. In some cases, it can also improve the adhesion of a starting material with a weak initial adhesion, as measured by the immersion-compression ratio. Finally, the presence of hydrated lime in the final mixture allows the mixture to benefit from the other functionalities of hydrated lime, namely reduced aged-hardening and improved mechanical properties [3,6,7,8].

3.2 Use of wet high surface area hydrated lime

It was also tried to see whether the pore structure of hydrated lime could have an effect on its use as a warm mix additive. In order to do so, we used a new wet hydrated lime (WHL2) was used. WHL2 comes from a special process developed by Lhoist which allows manufacturing hydrated lime with a higher surface area. The water content in the wet hydrated lime was still 20%. The results obtained by adding this new product in mixtures made with the river gravel (M1) are shown in Figure 4.

As can be seen from these data, the presence of a small amount of WHL2, namely 0.3%, in WMA M1 yielded a lower retained resistance than with the hot mix reference HMA M1 (Figure 4). In parallel, workability was deemed to be correct for WMA M1 with 0.3% of WHL2, that is similar to the HMA reference, as confirmed by their similar final densities. This behavior was similar to the one already observed with WHL1 (Figure 2).

When a higher amount of WHL2 was used (Figure 4), the exact same behavior has previously found with the same quantity of WHL1 (Figure 2) was also observed. Therefore, the data showed that WHL1 and WHL2 can be equivalently used to serve as a foaming agent, compacting aid and multifunctional additive in WMA.

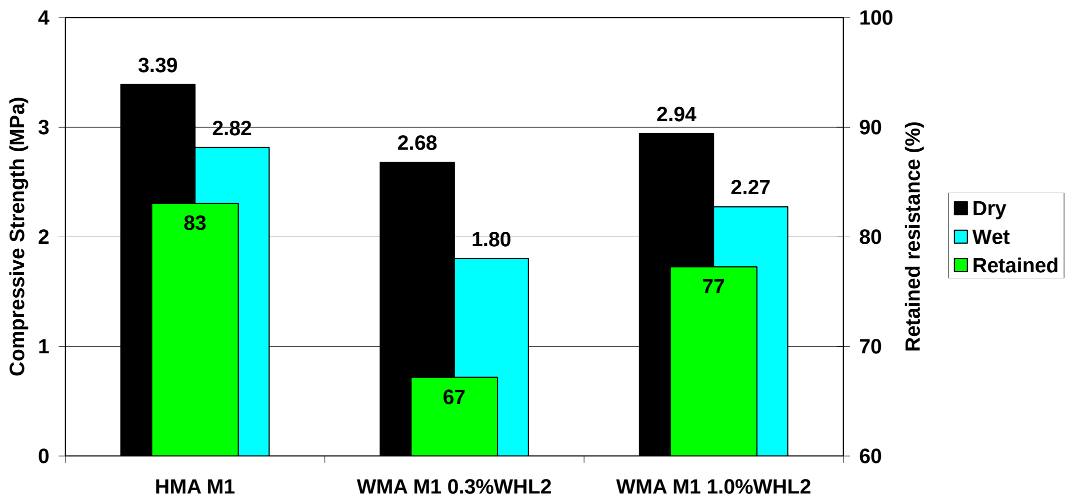

Figure 4: Dry and wet compressive strengths and retained resistance for HMA and WMA made of river gravel (M1 mixes). The WMA were made by using increasing amounts (0.3 to 1.0% based on aggregate) together with high surface area wet hydrated lime (WHL2) with 20% water.

4 CONCLUSIONS

In this work, the current situation of hydrated lime in Warm Mix Asphalts was reviewed. As a result, most WMA technologies, such as foamed bitumen, zeolites or waxes, were shown to be improved when hydrated lime was added. Still, it is recommended that WMA technologies making use of surfactants be checked in a mix design study in order to assess their compatibility with hydrated lime. If the surfactant is used as an adhesion promoter, then surfactant substitution by hydrated lime would probably be equally efficient. If the surfactant is used as a lubricant, then there is a risk of surfactant overconsumption due to adsorption on the hydrated lime particles.

A new way to use hydrated lime in the context of WMA is presented. The idea was to use wet hydrated lime instead of the dry hydrated lime currently used, in order to form a new class of foaming agents and compacting aids.

Two different wet hydrated limes have been used, one being a standard hydrated lime to which 20% water had been added and the other being a wet hydrated lime with high surface area coming from a specific process developed by Lhoist and already carrying 20% water. These two new warm mix additives were seen to perform well on two different aggregate sources, with additive content ranging from 0.3% to 1%.

As a conclusion, this work demonstrates that wet hydrated lime can be used as a warm mix additive. The advantage of this new class of additive is that, apart from its foaming-agent and compacting-aid role, it also retains the other functionalities of hydrated lime, namely improved bitumen-aggregate adhesion, reduced aged-hardening and improved mechanical properties. As a consequence, the detrimental effect of adding water in a warm-mix can be partially (Mixture 1) of fully (Mixture 2) compensated for by the presence of 1 % by weight of wet hydrated lime.

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