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EuLA, the European Lime Association, represents about 95% of the European lime production through its 21 national member associations. The European lime sector operates around 600 lime kilns in the EU, producing in total around 28,4 million tons of lime and dolime; and contributing around € 2,5 billion to Europe's GDP.

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Improved environmental footprint and road durability using hydrated lime in hot mix asphalt

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ABSTRACT

The evidence shows that adding hydrated lime to Hot Mix Asphalt (HMA) creates multiple benefits in the overall road performance (increased moisture sensitivity resistance, frost and rutting resistance, as well as an anti-aging agent for bitumen) and results in the extension of life span of asphalt pavements. A life cycle assessment (LCA) study comparing the environmental impact of the conventional Hot Mixed Asphalt (HMA) versus modified HMA (with 1.5% of hydrated lime) was carried out according to the ISO 14040-14044 standards and was validated by an external critical reviewer. The study shows that thanks to the use of hydrated lime in HMA the wearing course durability is extended by 25%, which leads to a decrease in the overall environmental footprint over the lifetime of a road (50 years) for all environmental impact categories.
If only road construction is considered, the conclusion would be that modified HMA has 19% higher GHG emissions compared to classical HMA. But once the full life cycle of the pavement is considered, with the improved durability also accounted for, then GHG are reduced by 23% in favour of modified HMA resulting in significant positive impacts. Therefore, it is very important that road pavements are evaluated over their whole life cycle if a holistic environmental picture is to be assessed. The modified HMA is the cheaper solution (by almost 30%) over 50 years. Moreover, it is worth reminding that each maintenance step avoided prevents the formation of traffic jams created by the maintenance works. This makes hydrated lime a sustainable and durable solution for better pavements. The conclusions of this study are in line with the recent EU initiatives on resource efficiency and sustainable construction, which require optimising the available financial and raw materials resources.

Keywords:

Life Cycle assessment (LCA); Hot Mix Asphalt (HMA); Road durability; Hydrated lime

Introduction

Lime is a product derived from limestone in an industrial process. Naturally occurring limestone, which is composed almost exclusively of calcium carbonate [$CaCO_3$], transforms into quicklime [calcium oxide (CaO)] by applying heat. When slaked with water, quicklime transforms into hydrated lime, which is a dry powder composed of calcium hydroxide [$Ca(OH)_2$]. Lime products are versatile materials that are used in many different applications, e.g. in industry, agriculture, environmental protection, civil engineering, etc.

Hydrated lime in Hot Mixed Asphalt (HMA) has been known to have several beneficial effects in the overall road performance (reduce moisture and frost damage, decrease bitumen ageing) which results in the extension of road durability. The European Lime Association (EuLA) has conducted a life cycle assessment (LCA) study to compare the environmental impact of the classical Hot Mixed Asphalt (HMA) versus modified HMA (with 1.5% of hydrated lime) for the lifetime of a road (Schlegel et al., 2012; 2016).

Hydrated lime has been known as an additive for asphalt mixtures from the late 19th century and from early road construction practices in the USA. Awareness of the effect of hydrated lime in HMA became clear during the 1970s in the USA. This was partly because of a general decrease in bitumen quality due to the petroleum crisis of 1973, when moisture and frost damage became some of the most pressing pavement failure modes of the time. Hydrated lime was tested and proved to be the most effective additive to increase the resistance to moisture and frost damage, decrease bitumen ageing, improving mechanical properties of the asphalt (such as stress, rutting resistance, fatigue and thermal cracking), thus extending the overall road durability. The experience from the North American State agencies estimated that hydrated lime at the range of 1-1.5% in the mixture (based on dry aggregate) increases the durability of asphalt mixtures by 2 to 10 years, or 20 to 50%. Because of these beneficial effects, hydrated lime is now specified in many States and it is estimated that 10% of the asphalt mixtures produced in the USA today contains hydrated lime. Since 1980 hydrated lime has increasingly being used in many European countries as well as other regions of the world. This is shown in the extensive literature review Lesueur (2011). The increase in overall traffic, frequent traffic jams, high density population, absence of space to build new roads and the environmental concerns arising from this situation have encouraged the European institutions and countries to revise their existing design and the road management practices through the Green Public Procurement (GPP) in Road Construction (EC, 2010 a; b). In addition, new initiatives on raw materials, sustainability principles and financial constrains require the optimisation of the available raw materials, financial and work force resources.

The Netherlands is the only European country where the use of hydrated lime is compulsory for use in HMA. Modified HMA in the Netherlands is around 7% compared to the total asphalt production. For other European countries, the use of modified HMA is generally below 1 % according to a detailed bibliographical review performed by the European Lime Association (EuLA) with data from various European countries (Lesueur, 2011; Lesueur et al, 2013). As an example, the French Northern motorway company, SANEF, currently specifies hydrated lime in the wearing courses of its network. They observed that hydrated lime modified asphalt mixtures have a 20-25% longer durability. Similar observations led the Netherlands to specify hydrated lime in porous asphalt, a type of mix that now covers 70% of the highways in the country. As a result of the national initiatives, hydrated lime is being increasingly used in asphalt mixtures in most European countries, in particular Austria, Denmark, France, Germany, the Netherlands, Poland, the United Kingdom and Switzerland. Based on the additional benefits of the hydrated lime, its use is likely to further increase in Europe in the years to follow.

The aim of this LCA study, undertaken by EuLA, is to assess and compare the environmental footprint of classical HMA (no hydrated lime) versus modified HMA (1.5% hydrated lime) during the full life cycle of a road. The study is conducted in line with the requirements of the ISO 14040-14044 standards (ISO 14040-14044, 2006 a; b) to ensure consistent, relevant data quality requirement and equivalent functional units.

Methodology

The scope of the study will consist of calculating the environmental footprint of classical HMA (No hydrated lime) versus lime modified HMA (1.5% Hydrated lime) as shown in Table 1. The LCA system boundaries cover the life cycle from cradle-to-grave for the HMA including: raw material extraction and transportation, HMA production and transportation, road construction, road maintenance, HMA recycling, end-of-life.

	Classical HMA (without lime addition)	Modified HMA (with lime addition)
Bitumen	5%	5%
Sand	38%	38%
Fine gravel	26%	26%
Coarse gravel	29%	29%
Filler	2%	0.5%
Hydrated lime	0%	1.5%

Table 1: Constituents of the classical and modified HMA

The primary raw materials used to manufacture classical and modified HMA are the same. The raw materials needed to produce the HMA are: bitumen, sand, fine gravel, coarse gravel and filler for the classical HMA and additionally hydrated lime for the modified HMA as described extensively in Schlegel et al (2016). The production of HMA consists in drying the minerals (sand and gravel) and heating them up to 180°C, mixing all materials (bitumen, minerals and optionally the hydrated lime). Depending on the technology used, this operation can be done in one or two steps. When the hot mix asphalt is ready, it is spread over the surface of the road.

Since the life span of the wearing layer, (the upper layer of the pavement) is much shorter than the lifetime of the road, the surface layer is maintained at regular intervals. The data for the maintenance scenario were taken from the LCA performed for the French Trade Association of road contractors (USIRF) by Bilal et al (2008; 2009). Based on information from the road constructors the life span of the surface layer is typically varying between 7 and 12 years. An average value of 10 years was selected for the modeling of this study. For the classical hot mix asphalt, the maintenance consists of a total thickness of 13cm added to the highway in the following steps:

After 10 years: 2.5cm HMA is placed on top of the initial wearing course;
After 20 years: milling of 4 cm HMA layer and placing of 8cm HMA layer;
After 30 years: same scenario as after 10 years;
After 40 years: same scenario as after 20 years;
At 50 years: end of life

If the same maintenance principles are also applied for the modified HMA as for the classical HMA, then the maintenance steps result in a total of 9cm added to the highway thickness in the following steps:

After 12.5years: 2.5cm HMA is placed on top of the initial wearing course;
After 25 years: milling of 4cm HMA layer and placing of 8cm HMA layer;
After 37.5 years: same scenario as after 12.5 years;
At 50 years: end of life.

The scenarios are both illustrated in Figure 1.

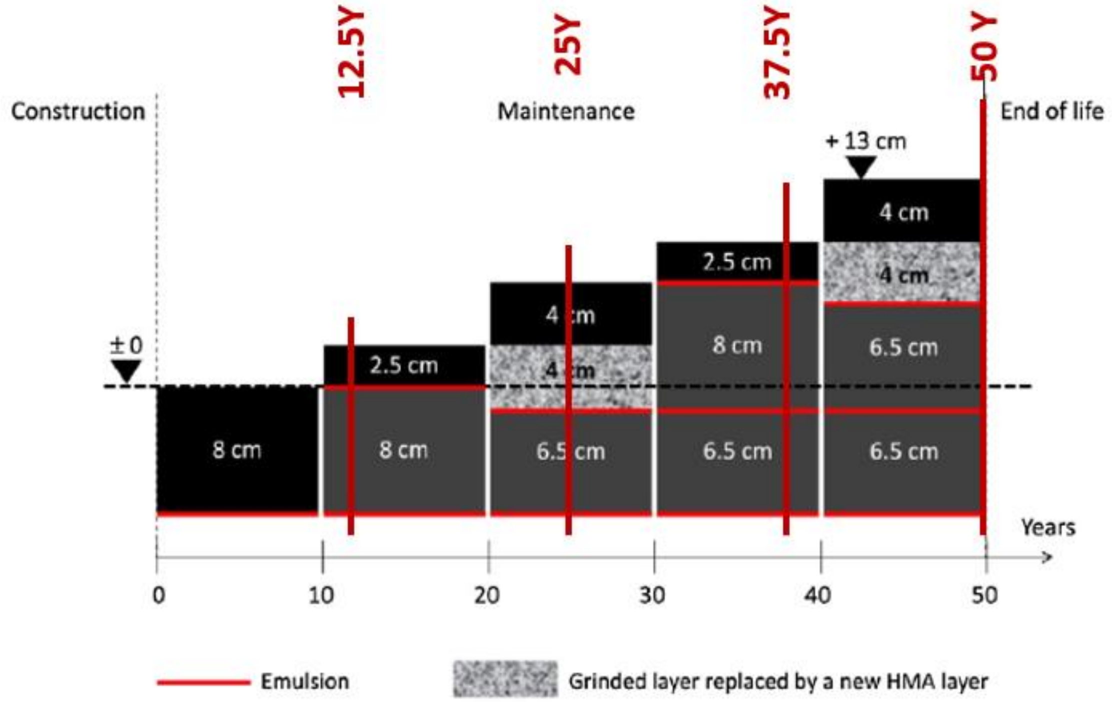

Figure 1: Summary of the different steps of the construction and maintenance of the wearing course of the classical HMA (without hydrated lime, background figure) and modified HMA (with hydrated lime, horizontal text in red above) as taken into account in the LCA model.

For the HMA recycling, the Reclaimed Asphalt Pavement (RAP) is shipped from the construction / maintenance site (road) to the HMA plant where it is fully reused according to the following scenarios: The first scenario covers 50% of raw material which are added into the new HMA. In the LCA model, it is assumed that the RAP replaces virgin bitumen, sand, gravel and filler that would have been otherwise purchased by the HMA plant from external production sites. Therefore, the credit that is accounted in the model includes the production of these materials as well as their avoided shipping;
In the second scenario 50% as sand and gravel are assumed for external use. In this case, it is assumed that potential users of sand and gravel will re-use the RAP as a substitute that they would have otherwise purchased from external production sites. Hence the credit considered in the LCA is limited to the production of the corresponding masses of sand and gravel.
The EuLA HMA LCA study is like the scenario published in Bilal et al, (2008; 2009). The main assumptions that the LCA study is based on are the following:

1. Lifetime of a road 50 years;
2. HMA layer 8cm;
3. Construction practice & maintenance scenario similar to the published LCA USIRF study Bilal et al, (2008; 2009);
4. Classical HMA has a life span of the surface layer of 10y; Maintenance every 10 years;
5. Modified HMA (+ 1.5% hydrated lime) increases the life span by 25% (road maintenance every 12.5y)

The functional unit chosen for the LCA study is: one French lane kilometre of road surface (wearing layer) with a width of 3.5 meters (thus representing a road surface of 3500 m2) and a functional life of 50 years (corresponding to the expected life span of the highway).
After comparison with other similar LCA's (University of Biberach, 2009; Sebben Paranhos, 2007), the assumptions on transport distances considered in this LCA are summarised in Table 2. Because the French LCA (Bilal et al., 2008) has highlighted the large variability of the shipping distances of the minerals consumed for producing HMA, the impact of these transportation distances on the LCA results was also assessed in the sensitivity analysis with other parameters.

Input flow	Main assumptions for modelling the transportation (base case) from production sites to HMA plant							Main assumptions for modelling the transportation (base case) HMA plant to construction site (construction and maintenance)	
	Bitumen	Bitumen emulsion	Sand	Fine gravel	Coarse gravel	Filler	Hydrated lime	HMA	RAP (Reclaimed Asphalt Pavement)
Type of transportation	Truck for bulk goods, Euro norm IV								
Maximum payload	27 tonnes								
Load factor	100% (full)[a]							100% (full)[b]	0% (empty)[b]
Load factor	0% (empty)[c]							0% (empty)[d]	100% (full)[d]
Average transportation distance (km)	500	500	50	50	50	150	250	500	500
Driving share urban (%)	0	0	0	0	0	0	0	0	0
Driving share interurban (%)	25	25	100	100	100	25	25	100	100
Driving share motorway (%)	75	75	0	0	0	75	75	0	0
Sulphur content of the fuel (ppm)	10								
% Bio fuel in diesel	0								
LCI database used	ELCD/GaBi 4.4								

[a] Load factor on the way back to the HMA plant.
[b] Load factor on the way to the construction site.
[c] Load factor on the way back from the HMA plant.
[d] Load factor on the way back to the HMA plant.

Table 2: Main assumptions for modelling the transportation.

Based on the ISO 14040-14044 requirements the outcome of the study was complemented with a sensitivity analysis. Some of the parameters which were modified were the following: 1. Use another LCI dataset to conduct the LCA; 2. Change energy consumption and type of fuels in the HMA plant; 3. Modify transport distances for aggregates and sand; 4. Change the maintenance intervals (for shorter or longer periods); 5. Increase the amount of hydrated lime used for the HMA. The result from the change of these parameters is that the modified HMA with hydrated lime always has a lower environmental footprint over the entire lifetime of a road. According to provisions set out in the ISO 14044 standard (ISO, 2006 a, b), the study passed the ex-post critical review by an external reviewer (TNO Utrecht, Netherlands).

Conclusions

Thanks to the 25% extension of the road durability, the use of hydrated lime in Hot Mix Asphalt leads to a decrease in the overall environmental footprint over the lifetime of a road (50 years), as show from this life cycle assessment using the ISO 14040-14044 standards. HMA with hydrated lime has a lower environmental footprint for most environmental impact categories for the above described assumptions. The primary total energy consumption is 43% less when the modified HMA is employed compared to the classical HMA. Road maintenance is the main contributor in terms of total energy consumption. The contribution of different processes in the primary total energy consumption are: in decreasing order of magnitude: The production of bitumen, the production of HMA, the fuel used by the trucks for the transportation (raw materials, HMA, RAP) and the fuel used for the mobile equipment (construction and maintenance). In addition, the modified HMA consumes much less resources than the option with classical HMA. The savings are like those observed for the energy consumptions. This can be easily explained by the fact that fossil fuels (in particular crude oil used for the productions of bitumen and diesel oil that is consumed by the trucks and the mobile equipment) contribute almost 99% to the abiotic resources depletion index. According to the Life Cycle Inventories, 90% to 93% of the GHG emissions are due to CO2 emissions.
Like the energy consumption, the road maintenance is the life cycle stage that contributes the most to the emissions of greenhouse gases (GHG). For the chosen end-of-life scenario, the option with the modified HMA leads to 23% less GHG emissions than the solution with the classical HMA. Even if another end-of-life scenario that would not provide any credit was assumed, the saving in GHG emissions would be around 14% as shown in Figure 2.

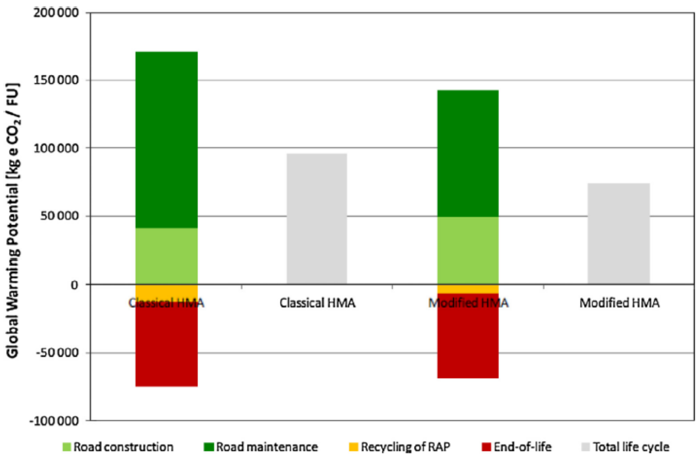

Figure 2: Global warming potential [kg eq. CO2)/FU].

The difference in the acidification potential between the two solutions is around 44% in favour of the solution with the modified HMA. The eutrophication potential is mainly attributed to the NOx emissions that lead to the formation of nitrates in the surface water. Therefore, all major combustion processes that emit nitrogen oxides (as listed previously) contribute indirectly to the eutrophication. The difference in the eutrophication potential between the two solutions is around 45% in favour of modified HMA.

For each maintenance step avoided, formation of traffic jams by the maintenance works is avoided. The results from this study have been validated by an external critical reviewer. The results from this study have an overall benefit for the sustainable development of the road construction sector. Additionally, the results of this study are in line with the recent EU initiatives on raw materials, sustainability principles and financial constrains which require optimising the available resources in raw materials, finance and work force.

Conclusions

The key outcome of the EuLA study is that the use of modified HMA in the wearing course clearly shows the lower environmental footprint for the main environmental impact categories: energy consumption, abiotic depletion, climate change, air acidification, photochemical oxidant formation, stratospheric ozone depletion and eutrophication. The increase in the lifespan by using the modified HMA is sufficiently large to avoid at least one road maintenance step during the life time of the road compared to the solution with the classical HMA. Moreover, it is worth reminding that each maintenance step avoided, prevents the formation of traffic jams created by the maintenance works.

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