DEVELOPING THE CASE FOR EXTENDING SERVICE LIFE OF ASPHALT SURFACINGS USING HYDRATED LIME

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ABSTRACT

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Hydrated lime is widely used internationally to increase the durability of asphalt mixtures through improved resistance to ageing and rut resistance, as well as mitigating aggregate stripping. This enables and helps maximise the use of local aggregates prone to stripping and avoids costly and often carbon intensive material movements. This paper provides a state-of-the-art review of the technical evidence on the use of hydrated lime in asphalt to extend the service life of asphalt surfacing. It summarises the technical, environmental and business elements of adding hydrated lime to asphalt mixtures and aims to quantify the benefits in a way that is meaningful to specifiers and asset managers, including resource and carbon benefits. This paper builds from the extensive literature review conducted by the European Lime Association (2011) and aims to provide an update in light of more recently published evidence.

Improving mechanical properties enhances the performance of asphalt mixtures, and reducing ageing improves durability, such that the frequency of maintenance interventions is lowered and the service life of pavements are extended. Increasing maintenance intervals assists in providing long term cost benefits and lowering environmental impact, as there would be lower environmental impacts from the maintenance interventions, and fewer emissions from the disrupted traffic associated with these interventions.

INTRODUCTION

Hydrated lime additions are well known internationally having been widely adopted for asphalt pavements for many applications and geographies. For example, hydrated lime is a normal addition for asphalts installed at airfields by the UK Government (Ministry of Defence, 2009) - known as 'Marshall Asphalts'; and are also common place in pavements in the Netherlands where porous asphalts are extensively deployed (van Vilsteren, 2017). Many of the State Highway Authorities across the USA have mandated the use of hydrated lime in asphalt mix designs (Little and Epps, 2001; Hazlett, 2017). Low level additions of hydrated lime are a key material in South African thin source course asphalt systems, to act as a filler and adhesion agent (Ojan, 2017). Although there is a substantial body of evidence that hydrated lime additions impart beneficial properties to the asphalt in service and extend the service life of pavements, its use is by no means universal.

Hydrated lime, or calcium hydroxide ($Ca(OH)_2$), is most commonly added to the asphalt mix at dosages rates of 1% to 2% by mass of aggregate, as a filler replacement. This can be achieved by various methods, e.g. directly into the drum; as a mixed filler; as dry powder to the damp aggregate; or as a lime slurry, often through standard and readily available equipment.

Both Highways England and the UK Specification for Marshall asphalt specify and require, respectively, hydrated lime conforming to BS EN 459-1 (Ministry of Defence, 2009; Highways England, 2019; British Standards Institution, 2015). Hydrated lime is defined in BS EN 459-1 as: "produced by the controlled slaking of quicklime; hydrated lime is available as powder, putty, or slurry or milk of lime." Highways England operates, maintains and improves England's motorways and major A roads.

The European Lime Association (2011) has produced an extensive literature review examining the use of hydrated lime as an asphalt addition and highlights the many benefits hydrated lime additions have on asphalt properties, which include;

- Increased moisture resistance;
- Improved ageing resistance;
- Enhanced stiffness and mechanical properties;
- Improved durability and longer service life.

This is echoed by Ojan et al (2017) who note that active fillers, such as hydrated lime and Portland cement, improve the stability of asphalt mixtures by stiffening the bitumen/filler mastic. They also note that whilst fly ash filler improves mix compactability, the physiochemical reactions of hydrated lime substantially reduces oxidation and ageing rate (Ojan et al, 2017).

Hydrated lime is also abundantly available across the globe as it is an important material used in a wide range of industrial applications including steel-making, construction mortar, water and wastewater treatment, control of incinerator and kiln emissions to air, agriculture and food production, as well as pharmaceuticals and plastics.

This paper does not seek to repeat the extensive literature review conducted by the European Lime Association (2011), but rather aims to provide a summary of evidence for specifiers and asset managers in light of new evidence that has been published more recently.

BENEFITS OF USING HYDRATED LIME ADDITIONS ON ASPHALT PROPERTIES

Moisture resistance

Moisture penetrating asphalt surface courses may result in a weakening of the bond between the aggregate and the bitumen in the mixture that can ultimately lead to stripping. Left uncorrected, in small areas, this results in potholes and over larger areas, cracks in the road surface, both of which allow water ingress to the lower layers of the pavement.

Since the first review conducted in the USA (Hicks, 1991), additions of hydrated lime have been noted as beneficial to preventing moisture damage in asphalt mixtures. This is widely accepted (Little and Epps, 2001) and has resulted in it being commonly specified with aggregates prone to 'stripping' (Hazlett, 2017). Discussions with a local authority in the South West of England indicate that the Council specifies the addition of hydrated lime in asphalt mixtures that contain locally available quartzite aggregates, or other aggregates requiring anti-strip measures (British Lime Association, 2018).

Researchers (Ishai and Craus, 1977) suggest that hydrated lime modifies the surface of siliceous aggregates by precipitating calcium ions on the surface, improving the bond between the aggregate and the bitumen in the asphalt. This is noted (Sebaaly et al, 2017) to be only one of the mechanisms operating in such mixtures, otherwise there would be no improvements seen with limestone mixtures.

Hydrated lime is widely added to asphalt mixtures across the USA as an ‘anti-strip’ agent (Little and Epps, 2001; Hazlett, 2017) and continues to gain favour as an addition for asphalt mixtures across Europe. It is perhaps unsurprising that it is extensively used in the Netherlands where a required addition for porous asphalt surface courses predominates (van Vilsteren, 2017) because porous asphalts, by their very nature, are more exposed to moisture and so more at risk of moisture damage.

Lesueur et al (2016) confirmed the benefits of hydrated lime additions by testing the compressive strength of asphalt mixtures made with granite, dry and wet after conditioning in a water bath at 18°C for 7 days. The results, shown in Table 1, show that with the addition of hydrated lime, the compressive strength is higher after conditioning. The hydrated lime was added as at 1% and 2% as a replacement for the filler.

Table 1. Compressive strength of asphalt concrete with granite aggregate, dry and wet after conditioning at 18°C for 7 days (Lesueur et al, 2016)

Asphalt mixture	Without hydrated lime	With 1% hydrated lime as a filler replacement	With 2% hydrated lime as a filler replacement
Compressive strength of dry sample (MPa)	8.5	8,8	9.0
Compressive strength of wet samples after conditioning (MPa)	7,3	8.3	8.7

Ageing resistance

During the process of mixing, laying and subsequent service life, the bitumen in asphalt becomes harder and more brittle increasing

the risks of defects such as surface cracking and ravelling (Soenen et al, 2016). Oxidation of bitumen within asphalt mixtures by exposure to atmospheric oxygen is known to affect the hardening of bitumen and so the durability of asphalt pavements.

Prompted by the observed ‘softening’ benefits in asphalt mixtures laid in Utah when hydrated lime had been added as an anti-strip agent, a study from 1968-1971 examined the viscosity and penetration of binders recovered from previously constructed pavements (up to six years old) and pavements especially constructed for the trial (Chachas et al, 1971). The study demonstrated that the viscosities were lower and the ductility increased for binders with hydrated lime additions compared to those without hydrated lime. The researchers concluded that the addition of one percent hydrated lime to bituminous mixtures was beneficial because it reduced the hardening rate of the asphalts. This lower hardening rate observed over time should not be confused with increased stiffness achieved through hydrated lime additions and discussed later in this paper. As highlighted above, hardening increases the risk of brittle defects, but the correct asphalt stiffness is needed to resist deformation of the asphalt under loading.

Five years later, a further investigation (Plancher et al, 1977), was undertaken to better understand the mechanisms through which hydrated lime additions reduce oxidative ageing. The study demonstrated that hydrated lime additions reduce the viscosity-increases associated with laboratory ageing by two separate and complimentary effects, namely:

- Adsorbing reactive polar compounds already present in the bitumen which influence its viscosity; and
- Reducing the formation of carbonyl-type oxidation products during ageing which affect bitumen viscosity.

Similar results have been obtained by other researchers (Edler et al, 1985; Petersen et al, 1987; Iwańskia and Mazurek, 2013; Zou et al, 2013; Banja et al, 2018).

Recent research at the University of Nottingham on UK materials tested mastics containing granite and containing limestone fillers, and tested mastics where hydrated lime replaced a portion of the granite or limestone filler (Airey et al, 2017). Samples were laboratory aged using thin film oven testing to BS EN 12607-2:2000 (British Standards Institution, 2000) and pressure ageing vessels at 90°C for 20 hours in accordance with BS EN 14769:2012 (British Standards Institution, 2012). In all cases, the ageing of the mastics containing hydrated lime were lower than the ageing of control mastics with filler alone. The researchers concluded two effects:

- Fewer carbonyl groups were formed on ageing in granite filler mastics containing hydrated lime– noted as the products of oxidative ageing; and
- The stiffness of mastics increased less on ageing when hydrated lime was included – that is, the ratio of the complex shear modulus (G*) before and after ageing was closer to one with hydrated lime additions than with granite or limestone filler alone – Figure 1, reproduced from Airey et al (2017).

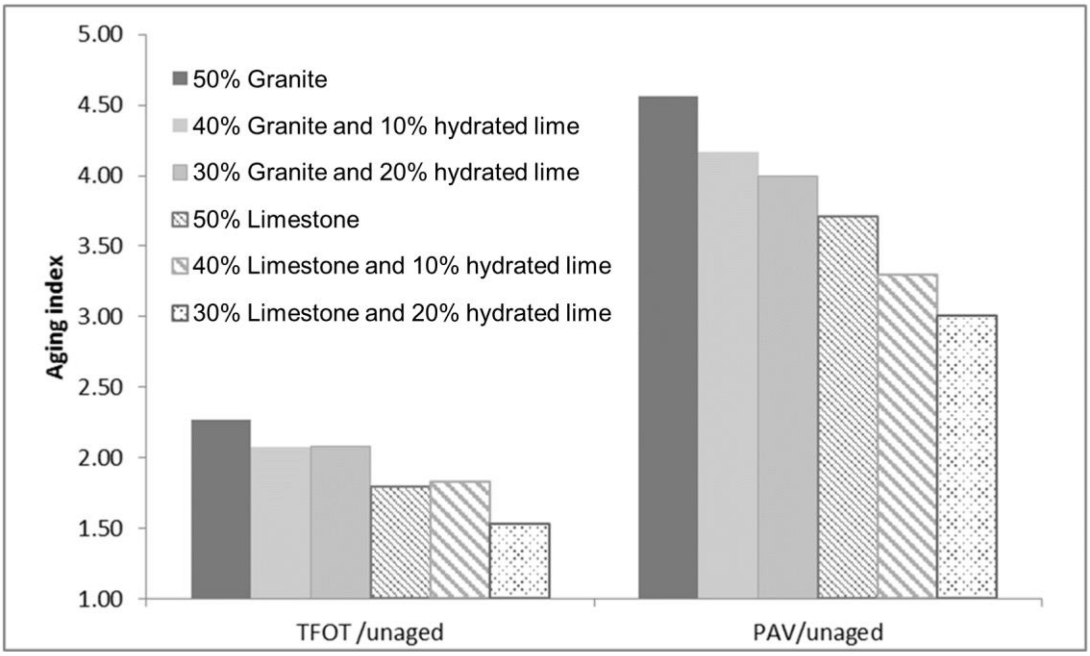

Figure 1. Ratio of complex shear modulus (ageing index) for mastics made with granite or limestone filler, with and without hydrated lime additions, after ageing by Thin Film Oven Test (TOFT) or Pressure Ageing Vessel (PAV) (reproduced from Airey et al, 2017)

Stiffness

It is reported in the literature (Lesueur et al, 2012) that hydrated lime stiffens the asphalt (essentially the bitumen and filler mixture) although the extent of the stiffening appears to be dependent on bitumen source, temperature, and time. At room temperature, the stiffening effect is similar to mineral fillers. This stiffening of the bitumen though hydrated lime additions, which has positive benefits for the mechanical properties of the asphalt, should not be confused with the effect of hydrated lime in lowering the hardening rate of bitumen, discussed previously.

By reviewing the published evidence of modulus testing of laboratory asphalt mixtures made with and without hydrated lime additions, the European Lime Association (2011) concluded that the modulus increased in around 60% of mixtures when hydrated lime was added. This may be a result of the noted variation in stiffness with measurement temperature and bitumen source. Similar results are observed for strength measurements, assumed to be for similar reasons (European Lime Association, 2011). Whilst the mechanisms governing stiffening with hydrated lime are not fully understood, it is known that the porosity of the hydrated lime addition and therefore the quantity of air voids in the mastic, has an effect (Lesueur et al, 2013). It has been suggested that at higher temperatures, above 'room temperature' where modulus is usually measured, the bitumen may fill the porous voids in the hydrated lime and so the particles behave in a similar manner to other mineral fillers with lower porosity, which means that the stiffness is enhanced (Lesueur et al, 2013).

Other mechanical properties

As a result of the improved stiffness, rutting resistance is improved in around 75% tested asphalt mixtures according to published literature (European Lime Association, 2011). In addition, field trials in Germany over 11 years have indicated improved rutting resistance where 2% hydrated lime was added to the asphalt mixtures (Lesueur et al, 2016).

Whilst there are fewer published studies concerning fatigue resistance, none of which use European Standard testing methods, it is evident in the published literature that, as with rutting resistance, fatigue resistance is noted to improve in 77% of the asphalt mixtures tested (European Lime Association, 2011). There are no identified changes in resistance to thermal cracking, or negative impacts reported (Lesueur et al, 2012). Ojan et al (2017) note that hydrated lime may decrease the severity of de-icing/anti-icing-related damage in susceptible mixes.

Durability and service life

Data on service lives of highways using hydrated lime additions was collected from various US states (Hicks and Scholz, 2003). This data has subsequently been combined with data from Poland and France (Iwańskia and Mazurek, 2012; Mabille, 2009) to establish median service life increases when hydrated lime is included in asphalt mixtures.

The authors have combined and reanalysed these data to allow the medians for different road types to be calculated over a larger dataset, as shown in Table 2. The calculations only consider data where comparison to a 'non-treated' road service life is possible. To avoid any skewing in the calculation of the median service lives and service life increase, the data for Utah in the USA dataset (Hicks and Scholz, 2003) were excluded as outliers. Similarly, the Oregon data in the USA dataset was also excluded as an outlier in the median calculation for service life and service life increase for low volume road.

This analysis demonstrates that, even when using a conservative approach where the calculation excludes 'high' increases in service life but does not exclude 'low' increases, the median increase in service life when hydrated lime is included in the asphalt mixture is 25%, when additions are between 0.7 and 1.5% (Hicks and Scholz, 2003). Whilst European information is limited in both the quantity of published data and the types of surfacing for which data has been made available, it does nonetheless, show that the service life improvement is similar to that experienced in the USA. It is helpful to note that some of the States represented in Table 2 have a similar climate to the UK. For example, Portland in Oregon experience similar temperature profiles to Manchester – albeit a few degrees warmed, and with similar average rainfall (World Meteorological Organization, 2020).

Furthermore, a 'worst case' improvement approach is achieved by using the lowest median service life increase for any group of highway data presented in Table 2. In this 'worst' case, the median service life increase for US low volume roads that achieve the upper range of anticipated service life, show a 10% increase in service life when using hydrated lime additions. Even using this extremely conservative approach, it shows that there is potential for at least 10% increase in service life when using hydrated lime in asphalt.

Table 2. Data on service lives of asphalt roads containing hydrated lime

USA DATA										
USA data (Hicks and Scholz, 2003)	**Service life without hydrated lime (yrs)**			**Service life with hydrated lime (yrs)**			**Change in service life with hydrated lime**			
							Increase in average SL		**Increase in upper SL**	
	Lower	**Average**	**Upper**	**Lower**	**Average**	**Upper**	**(yrs)**	**(%)**	**(yrs)**	**(%)**
Interstate roads										
Arizona	10	12	14	13	15	17	3	25%	3	21%
California	6	8	10	8	10	12	2	25%	2	20%
Colorado	6	8	10	8	10	12	2	25%	2	20%
Oregon	8	12	15	10	15	20	3	25%	5	33%
Texas	7	10	12	8	12	15	2	20%	3	25%
Utah	7	10	15	15	20	25	10	100%	10	67%
Median across interstate roads (excluding Utah data)							**2.5**	**25%**	**3**	**21%**
State and US highways										
Arizona	15	17	20	18	20	22	3	18%	2	10%
California	6	8	10	8	10	12	2	25%	2	20%
Nevada	6	8	10	10	12	14	4	50%	4	40%
Oregon	8	12	15	15	17	20	5	42%	5	33%
Texas	8	10	12	10	12	15	2	20%	3	25%
Utah	7	10	15	15	20	25	10	100%	10	67%
Median across State and US highways (excluding Utah data)							**3.5**	**25%**	**3.5**	**25%**
Low volume roads										
Arizona	15	20	25	20	25	30	5	25%	5	20%

Georgia	8	10	15	8	10	15	0	0%	0	0%
Nevada	12	15	18	18	20	22	5	33%	4	22%
Oregon	7	10	15	15	20	25	10	100%	10	67%
Texas	7	10	15	8	12	15	2	20%	0	0%
Utah	3	5	7	7	10	15	5	100%	8	114%
Median across low volume roads (excluding Oregon and Utah data)							**5**	**23%**	**4.5**	**10%**

EUROPEAN CASE STUDIES					
Country	**Road type**	**Reported service life without hydrated lime (yrs)**	**Reported service life with hydrated lime (yrs)**	**Increase in reported service life (yrs)**	**% increase in reported service life**
Poland (Iwańskia and Mazurek, 2012)	See Note 1	8	10	2	25%
Denmark (Mabille, 2009)	No information	100%	120%		20%
France (Mabille, 2009)	See Note 2			2	20%
Median for European case studies					**20%**
Median across all roads (based on USA and European Data)					**25%**

Note 1: Iwańskia and Mazurek (2012) note this road as having "L_{100} (ESAL - Equivalent Single Axial Loads) axle load of 100 kN per day per lane and it was calculated in the range from 336 to 1000".

Note 2: Mabille (2009) refers to SANEF, a motorway management company in the North and East of France (Société des Autoroutes du Nord et de l'Est de la France, 2020) using 1% hydrated lime additions.

GREENHOUSE GAS EMISSIONS AND CLIMATE CHANGE IMPACT

The life cycle assessment (LCA) over the assumed 50-year life of a hot mix asphalt (HMA) pavement shows lower whole-life greenhouse gas emissions when hydrated lime is added to the asphalt (Schlegel et al, 2016; Shtiza et al, 2017). A kilometre long, 3.5 m width carriageway was modelled, with and without hydrated lime additions in the surface course, using French specifications with a 1.5% hydrated lime addition as a filler replacement. The assumed increase in service life was the 25% median being from 10 years to 12.5 years. The LCA was conducted in accordance with BS EN ISO 14040 (British Standards Institutions, 2006).

The increase in service life associated with hydrated lime additions resulted in greenhouse gas emissions reductions of 23%, and a corresponding 43% reduction in primary energy consumption over the lifetime of the road. The saving is derived from the avoided material movements and consumption of materials resulting from the increased service life, (Schlegel et al, 2016; Shtiza et al, 2017).

Specifically, the model reports that greenhouse gas emissions of the assumed kilometre long, 3.5 m wide road reduced from 95,476 kgCO_2e to 73,655 kgCO_2e over the 50-year pavement life when 1.5% hydrated lime was included in the asphalt mixture – that is, a reduction of 21,821 kgCO_2e (Schlegel et al, 2016). This is equivalent to more than

200,000 km driven in a small, hybrid car (Department for Business, Energy and Industrial Strategy, 2019).

According to the UK Asphalt Industry Alliance, there are 36,371 km (22,600 miles) of road requiring maintenance in the next year or so in England (including London roads) and Wales (Asphalt Industry Alliance, 2019). Based on the LCA data (Schlegel et al, 2016), a 2.5-year increase in service life, typically achieved using hydrated lime additions to asphalt surface course mixtures, could avoid more than 1.5 million tCO_2e over the next 50 years for resurfacing of these asphalt roads. Hence, the extended service life achieved by using hydrated lime in asphalt can contribute to developing a UK and European economies that have net zero greenhouse gas emissions by 2050 (UK Government, 2019; European Commission, 2019).

It is important to note that the LCA was a 'cradle to grave' assessment, which means that all the greenhouse gas emissions associated with material manufacture and transport were taken into account, as well as the emissions associated with construction and maintenance, until the end of life (Schlegel et al, 2016).

The British Lime Association (2019) publishes an annual Sustainable Development Report that includes the carbon dioxide (CO_2) emissions associated with manufacturing in the UK – 906 $kgCO_2$ per tonne of quicklime manufactured in 2018. Quicklime (CaO) is around 75% of the compositional mass of hydrated lime ($Ca(OH)_2$) – so the CO_2 emissions of hydrated lime will, at minimum, be around 686 $kgCO_2$ per tonne of hydrated lime, based on 2018 manufacturing data. At an addition rate of 1.5% hydrated lime by mass of aggregate, there would be an embodied CO_2 increase estimated to be between 10.3 kg and 13.5 kg CO_2 per tonne of asphalt aggregate.

The 'cradle to grave' LCA clearly shows that the saving of 21,821 $kgCO_2e$ over the 50-year lifetime of the modelled highway when hydrated lime additions are made, is a saving that is achieved even when the additional CO_2 emissions of hydrated lime manufacturing are taken into account (Schlegel et al, 2016). This highlights the perverse environmental outcomes that are possible if only the climate change impacts of construction are considered, and not the whole life impacts (Schlegel et al, 2016) and if the decisions are made based on the construction project costs and environmental impacts without considering the maintenance costs and environmental impacts.

The LCA model does not however consider the emissions associated with traffic disruption during maintenance interventions. Whilst it is challenging to assess these potential greenhouse gas impacts, recent research shows that routine road congestion can increase the carbon emissions associated with road-deliveries by 2.5% (Kellner, 2016).

This confirms that the disruption caused by maintenance interventions will have a negative climate change impact, and that the impact will be lowered by extending service life and reducing the number of maintenance interventions. This further supports the notion that, if traffic emissions were taken into account, a 2.5-year increase in service life achieved by including hydrated lime in the asphalt mixture, would more than account for the greenhouse gas emissions associated with hydrated lime manufacturing using current technology. The lime industry, in common with other industries, is working hard to address greenhouse gas emissions and therefore the benefits of using hydrated lime in asphalt should improve as the lime industry decarbonises – for example, through the use of hydrogen fuels (Department for Business, Energy and Industrial Strategy, 2020; Mineral Products Association, 2020).

Even if the 'worst case' service life increases are achieved through the addition of hydrated lime to asphalt, there is a 10% service life extension between maintenance intervals, and there are still carbon benefits to be achieved. Whilst there is no reduction in the number of maintenance interventions over the 50-year lifespan in this scenario it logically follows that at year 50 the pavement will still have 5 years' service life remaining

RESOURCE EFFICIENCY BENEFITS

In accordance with international standards, the LCA included sensitivity (Schlegel et al, 2016). In all instances, the hydrated lime asphalt mixtures were beneficial for lowering whole life maintenance and greenhouse gas emissions remained true. The sensitivity analysis considered (Schlegel et al, 2016):

- Using a different LCA database for bitumen;
- Assuming a lower energy asphalt plant;
- Modifying transport distances;
- Modifying maintenance intervals.

Furthermore, when sand and aggregate transport distances are increased from 50 km in the LCA base case, to 200 km in the LCA sensitivity case, the greenhouse gas emissions associated with each kilometre long and 3.5 m wide carriageway increased:

- from 95,476 kgCO_2e to 105,633 kgCO_2e for asphalt without hydrated lime; and
- from 73,655 kgCO_2e to 79,128 kgCO_2e for asphalt with hydrated lime.

This highlights the importance of minimising transport distance in order to minimise environmental impacts – that is, it is most 'efficient' to use local aggregates in asphalt and source materials responsibly. As noted previously, hydrated lime is accepted to behave as an anti-strip agent (Little and Epps, 2001; Hazlett, 2017) and so can enable the use of more local materials in highways as well as providing durability and other performance benefits.

It is worth nothing that, whilst the LCA considered the environmental benefits of recycling asphalt into the maintained surface courses, it did not consider any service life, or carbon benefits, of recycling the hydrated lime content in the asphalt. There is some evidence (Ritter et al, 2016) that asphalt mixtures that contain hydrated lime as a result of recycling asphalt, show durability improvements, suggesting that the hydrated lime continues to have a beneficial effect beyond its initial design life.

ACCOUNTING FOR EXTENDED SERVICE LIFE

The document "Service life of asphalt materials for asset management purposes" is used by UK Highways Authorities responsible for the local road network as a means for lifecycle planning and asset valuation (Association of Directors of Environment, Economy, Planning and Transportation, 2015).

The BLA service life analysis in Table 2 shows a 25% median increase in service life – to provide a conservative approach, this median calculation excludes 'high' increases in service life but does not exclude 'low' increases. Applying this median improvement to the material service lives presented in the document "Service life of asphalt materials for asset management purposes" (Association of Directors of Environment, Economy, Planning and Transportation, 2015) gives the potential service lives for hydrated lime asphalt mixtures – Table 3.

Table 3. Service life of asphalt materials that achieve a 25% median increase in service life through hydrated lime additions

Material	Material service life in designed roads	Material service life in evolved roads	Potential material with hydrated lime service life in designed roads	Potential material with hydrated lime service life in evolved roads
(Association of Directors of Environment, Economy, Planning and Transportation, 2015)				
Asphalt concrete	8 years	6 years	10 years	7.5 years
HRA	20 years	20 years	25 years	25 years
Thin surface course system	15 years	10 years	18.75 years	12.5 years
SMA - Low texture	20 years	20 years	25 years	25 years
SMA - Other	15 years	10 years	18.75 years	12.5 years

The actual service life of a highway will be affected by compromising factors such as (Association of Directors of Environment, Economy, Planning and Transportation, 2015):

- Night work
- Wrong material in wrong place
- Use of non-Sector Scheme registered contractor
- Incorrect preparation of works
- Inclement weather conditions
- Surface conditions - such as no standing water; no residual salt; no detritus, and vegetation free
- Application to planed surface
- Compaction
- Segregation
- Poor substrate
- Poor finish / longitudinal profile
- Incorrect bond coat

If required, a 'worst case' improvement approach is achieved by using the lowest median service life increase for any group of highway data presented in Table 2. In this 'worst' case, the median service life increase for US low volume roads that achieve the upper range of anticipated service life show a 10% increase in service life when using hydrated lime additions. Using this 'worst case' approach, this gives the potential service lives for hydrated lime asphalt mixtures – Table 4.

Table 4. Service life of asphalt materials that achieve a 10% median increase in service life through hydrated lime additions

Material	**Material service life in designed roads**	**Material service life in evolved roads**	**Conservative material with hydrated lime service life in designed roads**	**Conservative material with hydrated lime service life in evolved roads**
(Association of Directors of Environment, Economy, Planning and Transportation, 2015)				
Asphalt concrete	8 years	6 years	8.8 years	6.6 years
HRA	20 years	20 years	22 years	22 years
Thin surface course system	15 years	10 years	16.5 years	11 years
SMA - Low texture	20 years	20 years	22 years	22 years
SMA - Other	15 years	10 years	16.5 years	11 years

CONCLUSIONS

The incentives outlined in this paper, when coupled with the lowered climate change impacts and potential to maximise the use of local materials, makes a compelling case that should encourage asset managers to consider hydrated lime additions in asphalt mixture specifications for their highway and other asphalt pavements.

This paper highlights that additions of hydrated lime to asphalt are considered as a standard addition for many kilometres of pavements in countries around the world. Many research and field evaluations have demonstrated that hydrated lime addition is a viable, practical means to reduce the rate of bitumen hardening, enhance stiffness and mechanical properties, improve durability, and extend the service life of asphalt mixtures.

From this experience, asset owners have suggested that service life will be extended, by 25% - the median expectation from these asset owners. Through lifecycle assessment modelling, this median service life extension has been shown to reduce the climate change impact of highway surface course maintenance by 23% over a 50-year pavement life. This would equate to a reduction of more than 1.5 million tCO_2e over the next 50 years if the service life extension was achieved for the 36,371 km of roads in England and Wales that are thought to be in need of maintenance in the next few years. Reductions in maintenance interventions lower the whole life costs of highways. Lifecycle assessment work has also highlighted the benefit of using local aggregates suitable for surface courses, which is enabled by the use of hydrated lime where aggregate stripping is a barrier to use.

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