Increasing the durability of asphalt mixtures by hydrated lime addition: What mechanisms?

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INTRODUCTION

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 a multifunctional additive for asphalt mixtures:
•it improves moisture damage and freeze-thaw resistance,
•it reduces chemical ageing of the bitumen
•it improves the mechanical properties of the mix.

Given that all the above properties impact the durability of asphalt mixtures, road managers report that hydrated lime increases durability by 25%.

This paper explains why hydrated lime is so effective in asphalt mixtures.

ACTION ON THE AGGREGATE: SURFACE MODIFICATION

Siliceous aggregates have worst adhesive properties toward bitumen than limestone. **Therefore, adding hydrated lime allows for the precipitation of calcium ions onto the aggregate surface, making it more favourable to bitumen adhesion (Figure 1 - [1]).**

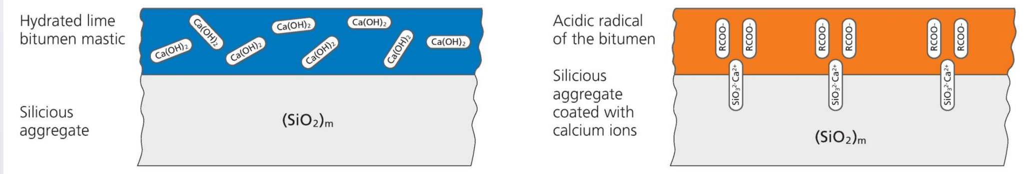


Figure 1: Effect of hydrated lime on the aggregate as proposed by I. Ishai and J. Craus [1]

ACTION ON THE AGGREGATE: CLAY FLOCCULATION

Hydrated lime is known to be highly effective in improving the resistance to moisture damage of clayey aggregates. In this case, the role of hydrated lime is similar to the one used for soil treatment: **lime flocculates the clay particles, preventing them to build a water-displaceable barrier between the bitumen and the aggregate.** A German study with controlled clay contamination confirmed that hydrated lime efficiently counteracts the effect of clay [2].

ACTION ON THE BITUMEN: CHEMICAL INTERACTIONS

• H. Plancher et al. at Western Research Institute (WY, USA) highlighted the chemical interactions between bitumen and hydrated lime: They took four bitumens and prepared 1:1:600 solutions of bitumen:hydrated lime:benzene that were left to react for 24 hours. The recovered lime-treated bitumens were weighted and analyzed by FTIR. About **4-6wt.% of each bitumen was strongly adsorbed onto the hydrated lime particles** [3].

• P. C. Hopman with the Netherlands Pavement Consulting showed in various solvents (n-heptane, THF, toluene and methylchloride) that **bitumen adsorption on active limestone filler containing 25wt.% hydrated lime was 1.4 and 2.1 times higher than with regular limestone filler**, for respectively Middle East and Venezuelan bitumens [4]. When comparing HP-GPC curves in toluene of the bitumens treated either with limestone filler or active filler (Figure 2), it appears that hydrated lime has adsorbed some of the heavy molecules of the bitumens.

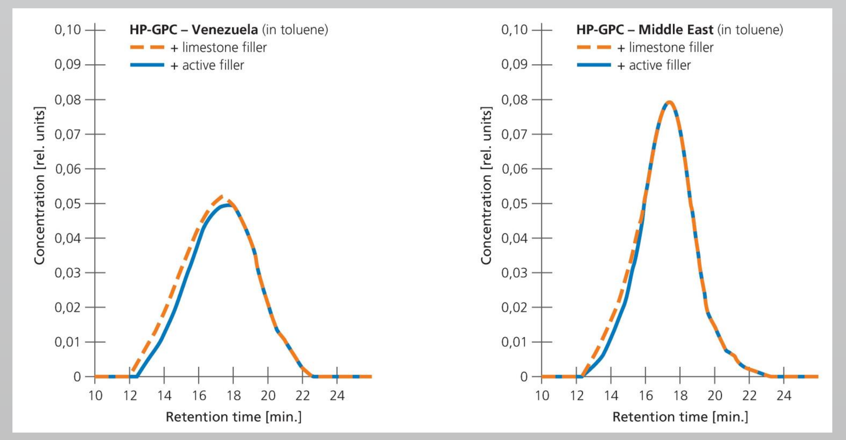


Figure 2: High Performance Gel Permeation Chromatography (HP-GPC) in toluene for two bitumens from Venezuela or Middle East after contact with either a limestone filler or the same filler with 25wt.% hydrated lime (active filler – adapted from [4]).

The lime-treated materials in the Plancher study showed lower concentrations in carboxylic acids, dicarboxylic anhydrides and 2-quinolones (Table 1 - [3]).

Asphalts	Concentration [moles/liter]				
	Ketones	Carboxylic acids	Dicarboxylic anhydrides	2-quinolone types	Sulfoxides
B-2959 without lime / with lime	0.015 0.039	trace (1)	0.0014 (1)	0.003 (1)	0.015 0.013
B-3036 without lime / with lime	0.021 0.039	trace (1)	0.001 (1)	0.001 (1)	0.022 0.019
B-3051 without lime / with lime	0.017 0.039	0.014 (1)	0.003 0.001	0.009 0.004	0.010 0.008
B-3602 without lime / with lime	0.045 0.1	0.06 (2) 0.014 (2)	(1) 0.007	0.011 0.006	0.015 0.015

Table 1: Concentration of functional groups in four AC-10 bitumens of different chemical composition before and after treatment by hydrated lime (adapted from [3]).

Clearly, **hydrated lime reacts with the acids, the anhydrides and the 2-quinolones of the bitumen**, as confirmed in another study [5]. 150g of 4 bitumens were left to react under agitation for 6 hours at 150°C with various amounts of hydrated lime or hydrated dolomitic lime. The materials with and without lime-treatment and before or after TFAAT ageing were characterized (Figure 3). As reproduced in Table 2, the presence of hydrated lime essentially reduces the amount of ketones and most of all of carboxylic acids that form upon ageing.

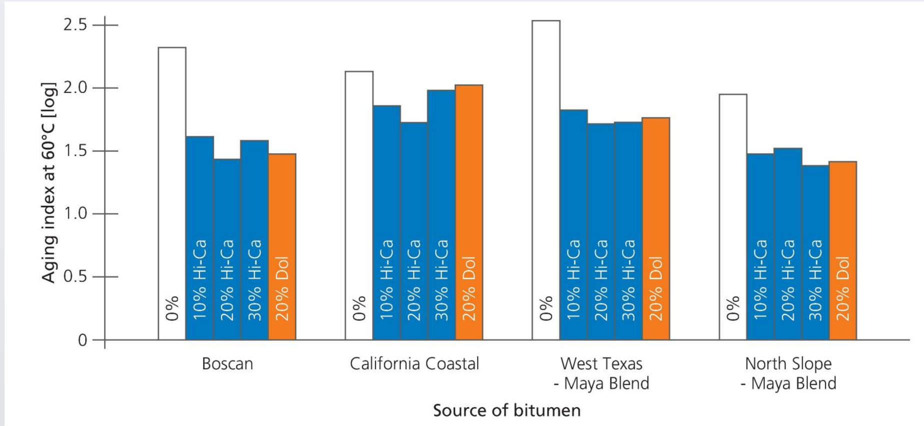


Figure 3: Aging index at 60°C for bitumens modified with different weight proportions of hydrated lime (Hi-Ca) and hydrated dolomitic lime (Dol). Ageing was performed in TFAAT (3 days at 113°C under air exchange – adapted from [5]).

Lime treatment		Aging test	Concentration [moles/liter]				
Type	%		Ketones	Anhydrides	Carboxylic acids	2-quinolone types	Sulfoxides
Without calcium	0	unaged	0	0	0.015	0.017	0.02
	0	aged	0.28	0.007	0.015	0.017	0.35
High calcium content	10	unaged	0.03	0	0.005	0.016	0.03
	10	aged	0.24	0.005	0.004	0.016	0.32
High calcium content	20	unaged	0.03	0	0.003	0.014	0.03
	20	aged	0.22	0.006	< 0.002	0.017	0.34
High calcium content	30	unaged	0.03	0	< 0.002	0.013	0.03
	30	aged	0.21	0.006	< 0.002	0.014	0.32
Dolomitic lime	20	unaged	0.03	0	0.006	0.013	0.03
	20	aged	0.22	0.006	0.005	0.014	0.34

Table 1: Concentration of functional groups in a Boscan bitumen before and after TFAAT ageing in the presence of various amounts of hydrated lime or hydrated dolomitic lime (adapted from [5]).

ACTION ON THE BITUMEN: PHYSICAL INTERACTIONS

Hydrated lime has higher voids in dry compacted filler (Rigden air voids) than mineral fillers, with typical values ranging from 60 to 70% when mineral fillers have values closer to 30-34%. The difference comes from the higher porosity of the hydrated lime particles (Figure 4). **Rigden air voids correlates very well with the stiffening power as measured by the delta Ring and Ball.**

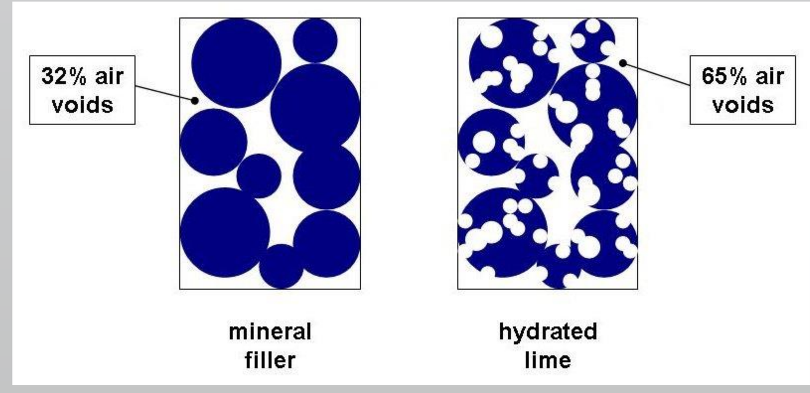
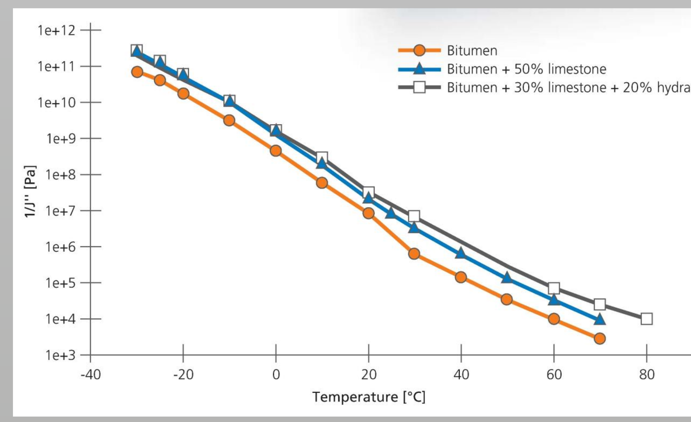


Figure 4: The dry porosity of hydrated lime (right) is higher than that of mineral filler (left) because the porosity inside the particles, which is negligible with mineral filler, sums up to the porosity between particles.

Interestingly, the stiffening effect observed with hydrated lime at high temperature disappears below room temperature, as observed by J. P. Wortelboer et al. (Figure 5 - [6]). This means that **the stiffening effect is not associated with an embrittlement at low temperature.**

Figure 5: Temperature dependence of the stiffening effect of hydrated lime as compared to limestone filler: inverse of the imaginary compliance (1/J") at 10 rad/s versus temperature for a 70/100 bitumen and with the same bitumen with 50wt.% of limestone filler or mixed limestone filler containing 40% hydrated lime (adapted from[6]).



CONCLUSION

Hydrated lime develops its benefits in asphalt mixtures from different mechanisms:

• Aggregate modification (surface precipitation of calcium ions and clay flocculation)
• Bitumen modification (neutralization of the acidic moieties of bitumen by the basic hydrated lime and stiffening effect due to its high porosity)

The aggregate modification generates an improved bitumen-aggregate adhesion. Moreover, the chemical interactions with the bitumen also participate in the improvement of the adhesive properties, by neutralizing the "bad" anionic adhesion promoters naturally present inside the bitumen.

Then, the chemical interaction with the bitumen results in the slowing down of the age hardening kinetics.

Finally, the high porosity of hydrated lime explains a stronger stiffening effect on bitumen than mineral fillers above room temperature.

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