Hydrated lime as additive for increased durability of asphalt mixes even after recycling

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ABSTRACT

The paper to be prepared presents the results of a laboratory testing programme on the beneficial effects of hydrated lime in binders of a recycled dense asphalt mix with a greywacke aggregate. The hypothesis is that hydrated lime slows down the ageing process of the asphalt mix. The test programme consisted of an ageing stage and a properties testing stage. Various cycles of preparing mixes, cooling down, heating up, mixing again, etc. were used to simulate the ageing process in practice. Only one type of dense asphalt mix was tested. Both mixes with and without hydrated lime in the binder were used.The degree of ageing was quantified after the ageing cycles 1 and 5. The asphalt specimens were gyratory compacted. The indirect tensile test was used for characterization of the strength of the asphalt mix. Due to ageing, the indirect tensile strength will increase with number of ageing cycle. Compared to the reference mix (without hydrated lime) the rate of increase of the mixes with hydrated lime in the binder was expected to be smaller than for the control mixes. The binder properties penetration and softening point were determined to support the effect.

Keywords: Additives, Ageing, Lime, Reclaimed asphalt pavement (RAP) Recycling, Testing

1 INTRODUCTION

For many years now, laboratory research projects and field experiences have demonstrated the beneficial effects of hydrated lime on the performance of asphalt mixtures [1]. The research and practical experience were based on freshly produced asphalt mixtures with hydrated lime. However, asphalt is a material which today is widely reused in many countries. Knowledge is lacked about the potential positive influence of hydrated lime in asphalt, when this asphalt is reused after years as a layer in a road construction.
To assess this research question a laboratory test programme was carried out. In this programme, two asphalt mixtures (AC 16 for surface course) were prepared with the same components (aggregates, filler, bitumen) and then aged. One of these asphalt mixtures contained additionally calcium hydroxide. Using these aged asphalt mixtures (without and with hydrated lime), new asphalt mixtures AC 16 were prepared and tested. When produced with fresh or recycled components, asphalt should have the same properties within the allowed tolerances. These properties may be compared. The influence of hydrated lime on the properties of the new asphalt mixture was examined by comparison of the two recycled asphalts in order to demonstrate that ageing of asphalt develops slower if hydrated lime is present, even if this component originates from recycled asphalt.
A simple laboratory ageing procedure made up by cyclic heating up, mixing and cooling down, was adopted to generate ageing of the mixture. This approach was found to be very effective.
Recycled asphalt mixtures composed of 50% aged asphalt containing hydrated lime and 50% fresh asphalt mixture were prepared using a Venezuelan as well as a Middle East bitumen.
The Indirect Tensile Test (ITT) on gyratory compacted specimens was adopted to quantify the ageing effect and implicitly the effect of the presence of hydrated lime. This test has been found to be discriminating for assessment of ageing effects. Apart from the Indirect Tensile Strength (ITS), fracture energy parameters derived from the ITT also appear to be appropriate to quantify ageing effects. The results of the ITT apply to the chosen composition of the asphalt mixtures. They are not directly transferable to other compositions of asphalt mixtures. However, they provide clues on the basic behavior of asphalt mixtures with RA and hydrated lime.
Recycled mixtures containing hydrated lime have been found to have diminished sensitivity to ageing. The research has shown that recycling of asphalt containing hydrated lime does not cause problems and performs to sustainable effects.

2 HYDRATED LIME

Hydrated lime is an inorganic compound consisting mainly of calcium hydroxide $Ca(OH)_2$. The required properties of hydrated lime for construction and civil engineering applications are specified in the European standard EN 459-1. The principal qualities of the various grades of hydrated products are summarized in Table 1 [2]. The letter "S", standing for "slaked", identifies hydrated products in powder form. Hydrated lime generally is available in form of a white powder. Quicklime cannot be used as a substitute for hydrated lime in asphalt. Quicklime reacts with moisture with increasing volume [3].

Table 1: Classification of calcic hydrated lime according to EN 459-1

Typ of Hydrated Lime	CaO + MgO	Available lime*
	wt.%	wt.%
CL 90-S	≥ 90	≥ 80
CL 80-S	≥ 80	≥ 65
CL 70-S	≥ 70	≥ 55
*The values for the available lime - calcium hydroxide [Ca (OH) 2] for hydrated lime - refer to the product when tested according to EN 459-2.		

Because of its mineral origin and particle size and distribution, hydrated lime is generally compared to mineral fillers in the asphalt industry. The European standards for asphalt (series EN 13108-1 through -7) [4] clearly specify: "filler includes materials as cement and hydrated lime". In this sense, hydrated lime can be evaluated using the specifications on aggregates for asphalt mixtures [5]. More precisely, the relevant part of this standard for hydrated lime is the one dealing with fillers. The case of mixed filler (mixture of filler and hydrated lime) is also described in this standard. The standard mainly considers the properties of the filler on their stiffening effects on the bitumen.

3 BENEFICIAL EFFECTS OF HYDRATED LIME IN RECYCLED ASPHALT

3.1 Reclaimed asphalt

Due to increased demands and limited availability of mineral aggregates and bitumen, asphalt producers discovered that reclaimed asphalt (RA) is a valuable component in asphalt. The two primary factors that drive the use of RA in asphalt pavements are economic savings and environmental benefits. RA is a useful alternative to virgin materials because it reduces the use of virgin aggregate consequently providing for conservation of our planet. RA also plays an important role in the reduction of virgin bitumen required in the production of asphalt. Briefly stated, the increase of RA in asphalt is of general interest. However, virgin bitumen cannot be substituted with the binder in RA without due consideration for the loss of bitumen properties due to oxidation and ageing. This phenomenon takes place over time and will generate a stiffer but more brittle asphalt mix.

3.2 Surplus value of hydrated lime in RA

The question whether hydrated lime, when present in RA, still has a continuing beneficial value in recycled asphalt mixes, should be answered through a test program to investigate the ageing of several bituminous mixes. A typical Dutch dense asphalt surface course mixture (AC 16 surf) was selected for this purpose. Various types of bitumen and filler and percentages of RA were investigated [6]. Wherever possible, EN standard test methods were applied. The conceptual approach of the research is presented in Table 2.

Table 2: Conceptual approach

Mixtures	The mineral aggregate fraction was composed by putting together washed fractions of the Greywacke components. Usually the filler used in an asphalt mix contains a small amount of dust generated by screening and rotating mineral aggregate particles during production. The washing process eliminates the dust from the aggregates so that only one filler from a single source will be used and investigated.
Mixture labelled MO (for reference)	Mixture AC 16 surf, not containing $Ca(OH)_2$
Mixture labelled MB (under test)	Recycled mixture AC 16 surf, composed of 50% aged mixture AC 16 surf (containing 25% $Ca(OH)_2$) and 50% fresh mixture AC 16 surf (not containing $Ca(OH)_2$). 25% of hydrated lime in an asphalt mixture is obtained by substitution of 25% v/v of the Viamix filler.
Coarse and fine aggregate	Greywacke (produced in Germany)
Bitumen	pen 70/100, Venezuelan and Middle East origin
Filler	Viamix 30 (fly-ash)
Hydrated Lime	CL 90-S, added to the filler (partly substitution of the filler)
Tests	Penetration, Softening Point ($T_{R\&B}$), $Ca(OH)_2$ content, Indirect Tensile Strength (ITS); all according to EN standard methods
Ageing method	Simulation of ageing during production by repeated heating-up, mixing and cooling down the mix (see 3.3)
Stages of ageing	AG1 and AG5 (see 3.3)

3.3 Ageing process

Table 3 presents the main work flow of the ageing process. Beware that this ageing process is not standardised as a normalized and regular method, but it is expected to simulate ageing during production of a mixture rather accurately (short term ageing). The asphalt is prepared according to EN 12697-35 [7] using the prescribed mixing time. Subsequently, the mixture is cooled down to room temperature and after that heated up again to the mixing temperature and mixed again during the prescribed time. This cycle of cooling down, heating up and mixing again is repeated to simulate different stages of ageing. During these cycles no changes are made to the mix composition. The applied stages of ageing are defined as:

- AG1 : mixture after the initial mix preparation (one cycle)
- AG5 : mixture after four extra cycles (in total five cycles)

Relevant properties of the aged asphalt mixture, like Penetration and Softening point Ring & Ball of the bitumen were measured before and after ageing. Tables 3 and 4 show that the procedure for accomplishing ageing appears to be really very effective.

Table 3: Ageing process

Step	Temperature [°C]	Time
Heating up to mixing temperature	155 ± 5	17 ± 1 hour
Mixing	155 ± 5	3 minutes
Cooling down to room temperature	20 ± 2	7 ± 1 hour
1 cycle of ageing	-	1 day

Table 4: Bitumen properties of mixes containing Venezuelan bitumen

Property	Unit	Fresh bitumen	MO1/AG1	MB1/AG1	MO1/AG5	MB1/AG5
Penetration	0.1mm	78	48	54	6	12
$T_{R\&B}$	°C	46.2	53.3	51.8	99.5	80.0
PI	-	-1.1	-0.5	-0.6	+2.4	+1.3

Table 5: Bitumen properties of mixes containing Middle East bitumen

Property	Unit	Fresh bitumen	MO2/AG1	MB2/AG1	MO2/AG5*	MB2/AG5
Penetration	0.1mm	83	50	53	-	17
$T_{R\&B}$	°C	46.2	50.0	49.9	-	71.7
PI	-	-1.0	-1.2	-1.1	-	+0.7
*MO2/AG5: specimen too stiff for accurate measurement of properties						

3.4 Indirect Tensile Test (ITT)

The Indirect Tensile Test (ITT) on gyratory compacted specimens [8] was used for quantification of the ageing effect and implicitly the effect of the presence of hydrated lime. The test temperature was set to 5ºC. This test has been found sufficiently discriminative for assessment of ageing effects. It was hypothesized that due to ageing the ITS value would increase as the bitumen becomes stiffer with the associated effect of stiffening of the asphalt the mix. Compared to the reference mixture (MO), the degree and rate of increase of the ITS value for mixtures MB containing $Ca(OH)_2$, should be less pronounced if $Ca(OH)_2$ really slows down ageing.

Apart from the Indirect Tensile Strength (ITS), fracture energy parameters derived from the ITT were determined as defined in Figure 1. These energy parameters are not defined in EN 12697-23. The parameters are derived from measuring the area under the load-deformation curve (being the work applied: N.mm) divided by the fracture area (mm^2) of the specimen. The resulting values represent a kind of normalized energy parameter (N/mm). The parameter E_1 may be associated with the amount of energy to initiate fracture, while E_2 may be associated with the amount of energy to resist total failure. A part of E_1 however, is elastic energy stored by the specimen and released at fracturing. These parameters sometimes are related to the concept of toughness of a material, although in materials science and metallurgy, toughness is the ability of a material to absorb energy and plastically deform without fracturing.

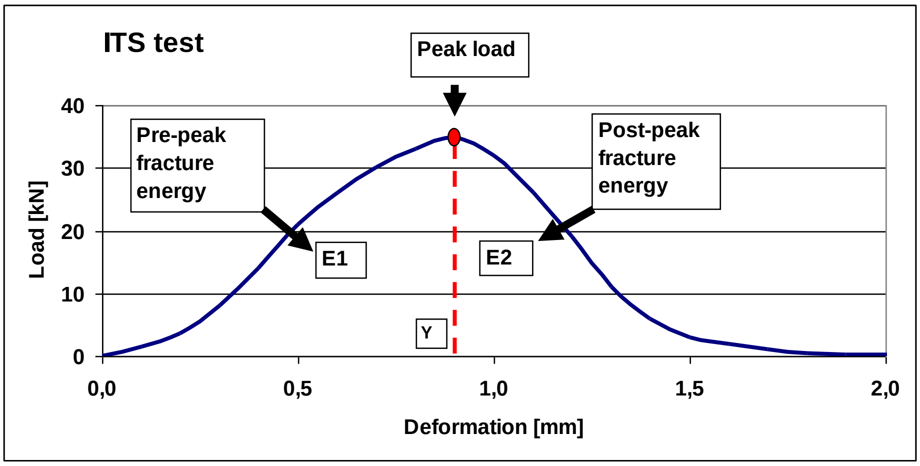

Figure 1: Interpretation of ITS test

3.5 Results

The following sections present the results found for the indirect tensile strength, the total fracture energy, and the pre-peak and post-peak fracture energies. The following symbols are used to denote the various mixes under investigation:

MO1 Mixture containing bitumen Venezuelan and no hydrated lime (reference)
MO2 Mixture containing bitumen Middle East and no hydrated lime (reference)
MB1 Recycled mixture containing bitumen Venezuelan and hydrated lime
MB2 Recycled mixture containing bitumen Middle East and hydrated lime

3.5.1 Indirect Tensile Strength

The results of the indirect tensile test are summarized in Figure 2. From the data may be observed that, after one ageing cycle only (ageing number 1) the mixtures containing the Middle East bitumen (MO2, MB2) tend to provide for higher values of ITS than the mixtures containing the Venezuelan bitumen (MO1, MB1). This is probably due to the type of bitumen, although differences between bitumen properties are limited.
The slopes of the lines of the mixtures containing hydrated lime are less steep that those of the reference mixtures (MB1 compared to MO1 and MB2 compared to MO2), showing that hydrated lime reduces increase of indirect tensile strength, or in other words, slows down the ageing process.

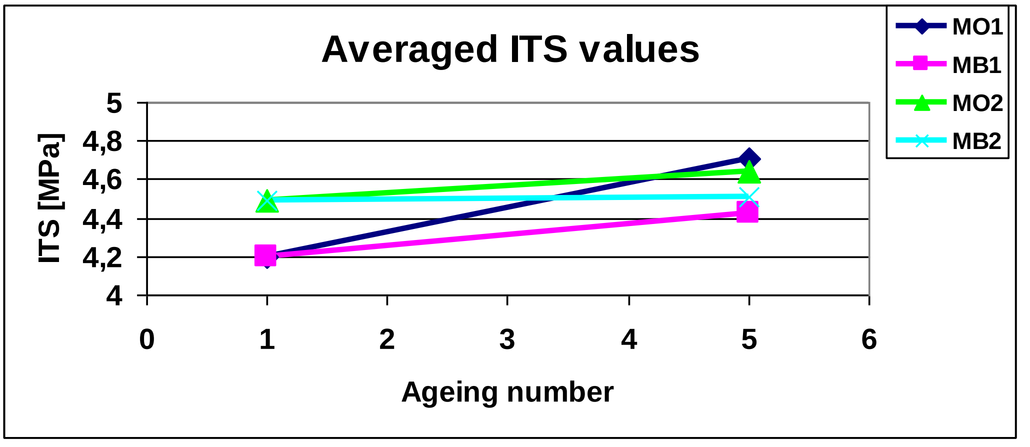

Figure 2: Relationship between ageing number and indirect tensile strength (ITS)

3.5.2 Total fracture energy (Etot)

The results of the total fracture energy computation are summarized in Figure 3. Due to similar test results, the data points for MB2 are hidden behind by the MO2 points.
As expected, all lines show a downward slope, pointing at increasing brittleness of asphalt mixtures with ageing. No specific influence of type of bitumen and filler can be seen when analysing the data. The hydrated lime in the Venezuelan mixture seems to provide for the smallest decline in total energy, which is the preferable condition. The hydrated lime in the Middle East mixture, however, shows the steepest line. The difference in slopes cannot be adequately explained.

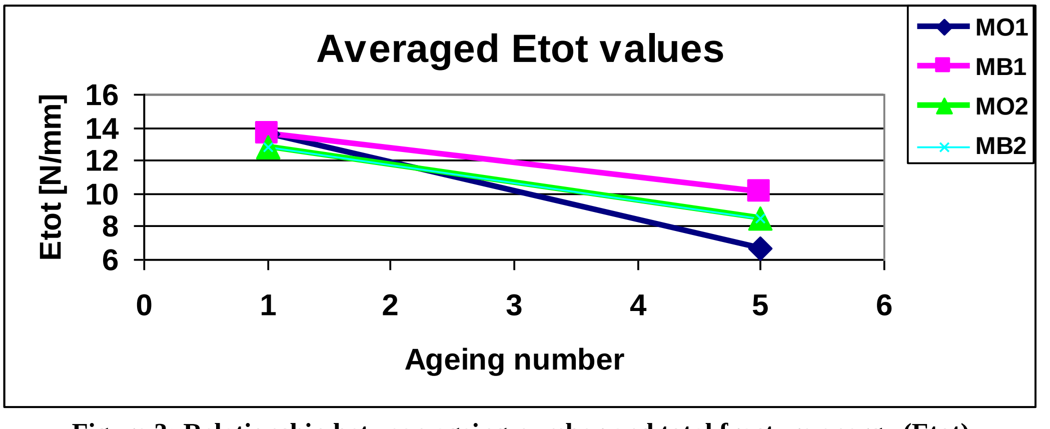

Figure 3: Relationship between ageing number and total fracture energy (Etot)

3.5.3 Pre-peak fracture energy (E1)

The results of the pre-peak energy computation are summarized in Figure 4. For most mixes, it can be concluded that the pre-peak fracture energy does not change with increasing number of ageing cycles. The pre-peak fracture energy also seems to be insensitive for the type of bitumen and filler, except in the case of the reference mixture with Venezuelan bitumen. The pre-peak fracture energy drops to a low value after ageing. No readily available explanation could be found for the measured results.

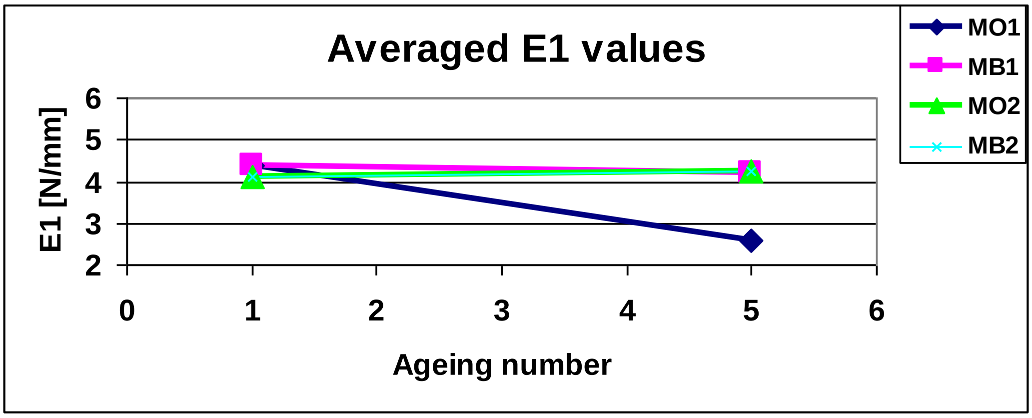

Figure 4: Relationship between ageing number and pre-peak fracture energy (E1)

3.5.4 Post-peak energy (E2)

The results of the post-peak fracture energy measurement are summarized in Figure 5. The lines denoted by MB1 and MB2 clearly are less steep that those for the MO1 and MO2 mixtures. The hydrated lime seems to have a beneficial effect on the post-peak fracture energy. This indicates that the mixtures containing hydrated lime stay more flexible that the reference mixtures. Preservation of flexibility is a mode of reducing the detrimental effect of ageing.

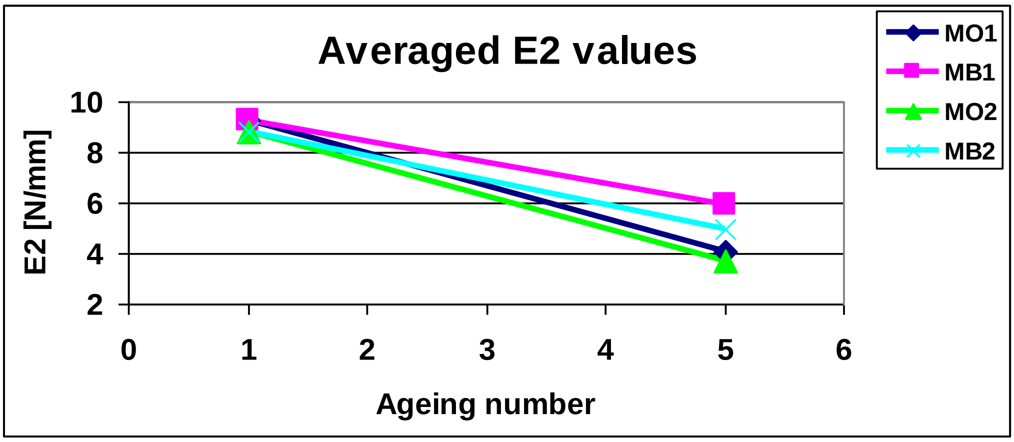

Figure 5: Relationship between ageing number and post-peak fracture energy (E2)

4 CONCLUSIONS

The various mechanical tests on asphalt, both with and without hydrated lime in the filler, resulted into data that point at favourable characteristics of that type of filler on the ageing of asphalt mixtures. The goal of the research program was to assess the impact of hydrated lime on recycled asphalt and to determine the sensitivity for type of bitumen and percentages of RA. Figure 2 to Figure 5 showed that heating up and cooling down asphalt clearly leads to increased strength due to hardening and to decreased fracture energy due to increased brittleness.
These two negative effects tend to be less in the case where hydrated lime is added in the filler. This leads to the conclusion that hydrated lime really may be seen as a means for improvement of the ageing characteristics of asphalt mixtures.

Evidence exists on the following beneficial effects:

- Hydrated lime in RA does not cause negative effects or problems at recycling and hydrated lime in RA yields sustainable effects in the recycled mixture
- Hydrated lime must be considered to be a multifunctional additive that increases the sustainability of asphalt mixtures.

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