Low Emission2 Asphalt Pavement, LE2AP

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ABSTRACT

This paper describes progress of the ongoing LE2AP project, acronym for Low Emission2 Asphalt Pavement, where 2 indicates that emission of pollutants during production and noise during usage are considered. LE2AP concentrates on a novel way of asphalt recycling. Key issues in the LE2AP approach are that the materials that become available in road reconstruction are valued. The first step is obtaining these materials by means of dry milling. Thereafter the reclaimed asphalty is decomposed into its components. As a result of this reclaimed stone aggregates hardly containing bitumen and a bitumen rich mortar sand - which is a mixture of bitumen, filler and sand - are obtained. The mortar sand is used as the main ingredient for the production of a standard mortar. The standard mortar is produced in an enclosed tank fitted with a stirring device. In this tank the mortar is homogenised and treated with rejuvenator and soft bitumen. The standard mortar has constant bitumen content and constant performance characteristic. The standard mortar may be used to produce many of the porous asphalt mixtures used in the Netherlands today. For the production of denser types of AC especially sand needs to be added. During mixture production the mortar is foamed and fed into the mixer where it is mixed with reclaimed stone to obtain a high-grade asphalt mixture containing a high percentage of reclaimed material produced at low temperature.

The LE2AP project is partially funded via a LIFE+ grant. LE2AP will come to completion in 2016 with the installation of 1 km of pavement surfacing that is produced at ≤80°C, results in ≥7 dB initial noise reduction and that contains ≥80% reclaimed material

In this paper the LE2AP approach is discussed and results obtained so far are shared. The main results that are discussed are the following.

- Decomposition of reclaimed asphalt into its components is feasible,

- Production of a high quality mortar with constant properties is feasible,

- The production of high quality porous asphalt, PA, comprising 93% reclaimed material is feasible,

- LE2AP PA mixtures containing 93% reclaimed material may well outperform their freshly produced peers, even when produced at reduced temperatures.

Keywords: Durability, Low-Temperature, Mixture design, Porous asphalt, Reclaimed asphalt pavement (RAP) Recycling

1. INTRODUCTION

BAM, the largest contractor in the Netherlands, aspires to play a leading role in product innovation and sustainability. The research and development department has therefore developed a vision taking into account future developments in the Dutch asphalt paving industry. This vision indicates that our industry is transforming from a construction industry to a reconstruction industry in which the importance of noise reduction, sustainability and 24/7 traffic flow will only increase. BAM's concept of the 3D-road: Duurzaam, Doorstroming en Decibellen (Sustainable, Traffic flow, Decibels) was derived on basis of this vision.
In the concept of the 3D-road it is of importance that asphalt can be recycled horizontally with high quality. This demands that high-quality asphalt mixtures comprising very high percentages of reclaimed asphalt are available in the future. To enable horizontal recycling of noise reducing Porous Asphalt, PA, surface layers the noise reducing properties of these mixtures should match the "state of the art". Apart from high percentages recycling, sustainability also demands that these mixtures can be produced at low temperatures to reduce emissions and limit the use of fossil fuels. Finally the demands with respect to traffic flow and traffic hindrance imply that asphalt recycling should preferably take place within the boundaries of the reconstruction site (not in-situ, but on-site). This dramatically reduces construction related traffic and thus limits traffic hindrance during reconstruction.
BAM foresees that it will have all techniques required for on-site, high-quality, horizontal asphalt recycling at low temperatures available 15 years from today. To demonstrate that this vision is realistic BAM submitted a request for LIFE+ subsidy with the European Committee (EC). The request was accepted and resulted in a € 1,3 million grant to execute the proposed LE2AP project, acronym for Low Emission^2 Asphalt Pavement. Where ^{2} indicates that emission of pollutants during production and noise during usage are considered. At the end of the LE2AP project one kilometre of noise reducing PA has to be installed. This surface layer should comprise ≥80% reclaimed material, result in ≥7dB initial noise reduction and should be produced at temperatures ≤80 °C.
In this paper the current status of the LE2AP project is discussed. It is explained that the followed new approach of asphalt recycling will allow for the low temperature production of high-quality mixtures containing high percentages of reclaimed material. It is shown that today PA mixtures may be made that contain 93% of reclaimed material and are at least equivalent in terms of performance to freshly produced PA mixtures. It is also shown that LE2AP is a firm step towards the innovative way of asphalt recycling that BAM envisions for 15 years from today.

Figure 1: The LE2AP and LIFE+ logos. Publication of the LIFE+ logo is mandatory by the European Committee

2. HORIZONTAL RECYCLING

Today reclaimed asphalt is re-used at relatively high rate in the Netherlands [1]. AC bin/base layers may comprise 50% to 60% reclaimed asphalt. However, reclaimed asphalt is not or hardly used in surface layers. To make matters worse, high quality material reclaimed from surface layers is often mixed with sand and cement to be reused in base courses.
LE2AP targets to break with this trend. Reclaimed asphalt retrieved high in a pavement structure should be re-cycled into an asphalt that may well be applied high in the new structure . Also the use of high quality material such as reclaimed asphalt for the construction of base courses should be limited. By using reclaimed asphalt in this way reuse becomes true horizontal recycling in which materials are re-cycled to fulfil a function that is equivalent to their original function. In the concept of horizontal recycling it is not necessary that reclaimed asphalt is re-used to produce the same mixture over and over again. Materials reclaimed from a PA surfacing might for instance be reused to produce an AC surf.

3. WITHOUT HEADING NO DESTINATION

BAM wants to give direction to her research activities and therefore developed a vision on future developments in the Dutch asphalt paving industry. Key points in this vision are:
1. The paving industry moves towards a reconstruction market,
2. High-quality reuse of raw materials thus is increasingly important,
3. The rate at which reclaimed AC is used in new mixtures should increase,
4. Reduction of traffic noise is increasingly important,
5. The environment in all her aspects should be spared,
6. Traffic hindrance should increasingly be prevented, especially during reconstruction works.

The vision summarised above provides a clear heading towards our goal:
   1. Reconstruction works represent an increasing part of the market; vision-point 1. Pavements that require reconstruction should be seen as a stock of raw materials needed for construction of the new pavement. These materials should be reused; vision-point 2.

2. In order to build a high-quality new pavement with the materials available on-site these raw materials should be reused at high recycling rate and in high-quality new mixtures; vision-point 2 & 3.
3. Traffic noise is an important issue. For this reason the reuse of reclaimed materials should be of such quality that high performance (noise reducing) PA layers can be produced on basis of reclaimed materials; vision-point 4.
4. Reuse of the reclaimed materials should be done at low temperatures, this saves energy and limits emissions; vision-point 5.
5. The reclaimed raw materials are located where they are needed, i.e. in the pavement to be reconstructed. Transport to and from an asphalt production plant should be prevented. This spares the environment and limits traffic hindrance: vision-point 5 & 6.

The above leads to the following goal.

In 15 years the collection of raw materials from old pavements will be an integral part of the asphalt paving industry. Milling of asphalt will then be equally important as asphalt production and installation is today. To allow for the production of high quality asphalt on basis of reclaimed material and at low temperatures dry milling is important. This is because build-in moisture is the enemy of high quality asphalt. Therefore the reclaimed asphalt is kept as dry as possible.

The reclaimed asphalt is then decomposed into its components. Apart from various fractions mineral aggregates that hardly contain bitumen, also bitumen rich mortar sand is obtained. The mortar sand is heated to 160-170°C and treated separate from the reclaimed aggregates. In this process the bitumen rich mortar sand is not brought into contact with a dryer drum burner flame or air as is the case in current day asphalt recycling. Because of this emissions are limited. Treatment involves adding soft bitumen, rejuvenator and homogenisation. If required also filler dust may be added. Issues of bitumen blending efficiency, homogeneity, oxidation or burning of bitumen, which are common issues in conventional asphalt recycling [1-3] are prevented. This new approach thus spares the environment and enhances the quality of new asphalt containing high percentages of reclaimed material.

The treated mortar sand provides a new product, i.e. a high quality and homogeneous LE2AP mortar; the bonding medium for new asphalt. Because the mortar is mixed and heated in a controlled process issues related to diffusion of the rejuvenator do not exist [11, 12].

The reclaimed mortar is then foamed and fed into to a mixer where it is mixed with reclaimed aggregates in various fractions as per mix recipe. Since there is full control over the quality of reclaimed materials and over the rates at which they are dosed this results in a high quality new asphalt comprising high percentages reclaimed asphalt.

The dry reclaimed aggregates are or not or only partially heated. By keeping moisture out of the system dryer drums may eventually no longer be required. This makes the on-site production of high quality asphalt containing high percentages of reclaimed asphalt feasible. Much of the transport which today takes place during asphalt road construction may then be omitted, in larger projects transport will be limited to transport within the parameters of the reconstruction site only.

Since the reclaimed asphalt is divided into its components the sketched process of asphalt recycling is not only applicable for the production of AC bin/base mixtures. Also mixtures such as AC surf, Porous Asphalt and Stone Mastic Asphalt may then be produced at low temperature and according to recipe and with control over the quality of used reclaimed materials. This enables for true horizontal recycling of asphalt.

4. LE2AP

The LE2AP horizon does not reach as far as the process described above in the sense that within LE2AP dryer drums are still required to head reclaimed aggregates to a temperature of 80°C. This implies that LE2AP does not target on the described on-site recycling. The LE2AP project, however, lies on the path that may well lead to on-site recycling without the use of dryer drums. The goal of LE2AP is to install 1 km of surface layer with ≥7 dB noise reduction, ≥ 80% recycling and produced at ≤80°C with significant reduction of emissions. The production of this surface layer should furthermore result in significant reduction of energy usage and emissions. The main steps in LE2AP are discussed hereafter and achieved results are presented.

5. DRY MILLING

Build-in moisture is the enemy of quality asphalt mixtures. If asphalt is to be produced at temperatures below 100°C less moisture can be evaporated during production. If quality asphalt is to be produced on basis of reclaimed materials at low temperatures it is therefore important that the reclaimed materials are as dry as possible. Milling techniques that may require significantly less water than common techniques are tested in collaboration with Freesmij (the largest Dutch contractor in AC milling) as this paper is written, see Figure 2. For reasons of brevity obtained results are summarised.

Tests indicated that today approximately 1% of water is used during milling of asphalt in the Netherlands. This percentage is not dependable on the type of asphalt that is milled off. Tests indicated that water consumption may be reduced by 25% to 0.75% when a dust collection system is used without consequence on chisel service life. Further test with diamond chisels are expected to show that the water usage may be reduced further when diamond chisels are used.

However, it was also found that milled off asphalt stored in the open on average contains 3.5% moisture. This leads to the conclusion that most of the moisture in milled off asphalt comes from rainfall and not from milling. Roofed storing of milled off asphalt is thus the more effective way to reduce the moisture content in reclaimed asphalt.

Figure 2: Left: water pressure and flow gauge mounted on milling machine. Right: inspection of chisel wear during measurements

6. DRY DECOMPOSITION

Milled off asphalt has a given composition that, per definition, does not comply with the recipe of a new mixture. Furthermore the bitumen in the reclaimed asphalt has aged, this is especially the case with PA surface layers. Nowadays standard AC bin/base layers produced in the Netherlands contain 50% to 60% reclaimed asphalt. AC bin/base layers that contain even more reclaimed asphalt are incidentally produced and installed. In the Netherlands surface layers contain no, or very limited, amounts of reclaimed asphalt.
At the mentioned percentages of reclaimed asphalt usage the rate of fresh materials added to the mixtures is high enough to keep control over mix composition: mineral grading and bitumen percentage of the end product. Furthermore the rate at which fresh bitumen is added is such that a mixture with sufficient quality is obtained. Finally existing techniques for asphalt recycling at ≥30% are not applied in the major league of asphalt recycling, i.e. recycling of surface layers.
In the future we need to be able to produce high quality asphalt on basis of reclaimed material. This demands for recycling percentages of about 95%. Such recycling should not only apply for AC bin/base mixtures, but especially so for surface layers.
Recycling at such high rates is only feasible when reclaimed asphalt is decomposed into mineral aggregates in various fractions and mortar sand. By selective milling high quality aggregates from surface layers may be kept separated from other, softer aggregates. The retrieved mortar sand undergoes a separate process in which it is treated and homogenised to obtain a quality mortar to be used for the production of new asphalt.

Figure 3: Full-scale decomposition of reclaimed asphalt

The process of decomposing reclaimed asphalt is mastered, see Figure 3. In this process use is made of the properties of bitumen: chewing gum behaviour at low frequencies and more important, glass-like behaviour at high frequencies. In the decomposition process milled off asphalt is thrown against a steel wall. The impact results in extremely high load frequencies. As a result the bitumen and mortar show glass-like behaviour at impact. Brittle failure is a result of that and the mortar film that surrounds individual aggregates is peeled off consequently. The result of this process is a de-bonded mix of aggregates hardly containing bitumen (<1% “in” (m/m)) and a bitumen rich (10-12% “in” (m/m)) mortar sand, see Figure 4. By utilisation of sieving techniques the mortar sand <2 mm is separated from the mineral aggregates >2 mm.

Figure 4: By decomposition of reclaimed AC new commodities become available. Left: mortar sand (sand, filler and bitumen), right: mineral aggregates in various fractions that hardly contain bitumen

By control over the speed of impact the decomposition process is optimised such that the grading of the reclaimed stone is not much affected (see Figure 5) whilst the bitumen content on these stones remains limited. This automatically leads to a high quality reclaimed mortar sand.

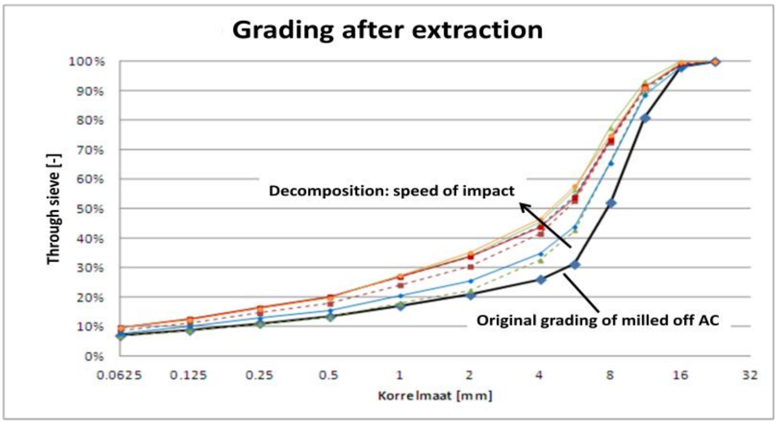

Figure 5: Reclaimed asphalt is decomposed by impact. By controlling the speed at impact an optimum is found: aggregates that are free of bitumen without jeopardizing mineral grading

7. MORTAR DESIGN & PERFORMANCE

7.1. Introduction

In LE2AP the aim is to produce high quality asphalt mixtures that in terms of performance at least equal freshly produced mixtures. It is believed that much scientific knowledge about asphalt behaviour is available. However, it is also believed that asphalt remains a mysterious material which behaviour cannot fully be explained on basis of science. Therefor in LE2AP the approach is to strive for equality on three levels of scale:

- Bitumen: Scale of molecules,
- Mortar: Meso scale, i.e. the scale of small particles <2 mm,
- Mixture: Bulk scale, i.e. the scale of the complete mixture <22 mm.

The mortar sand is treated and homogenised in an enclosed tank with stirring device. In this process a high quality mortar with constant properties should be produced. The first step to reach this goal is to ensure that the bitumen in the produced LE2AP mortar is of the same quality as fresh bitumen. Hereto a Viscous Fluid Design method is required. The Viscous Fluid Design method is later used to guarantee bitumen quality by controlling the rate of rejuvenator and fresh bitumen application. The Viscous Fluid Design method is also used to control the bitumen content of the produced mortar. The Viscous Fluid Design method should be simple for use in company practice and is therefore based on interpretation of pen-values only.

The second demand is that the obtained LE2AP mortar equals a freshly produced mortar. To obtain such mortar a Mortar Design method is developed under the restriction that the bitumen content in LE2AP mortar should equal that of a fresh mortar. The Mortar Design method was developed considering the response behaviour of virgin mortar determined by use of the Dynamic Shear Rheometer, DSR, only. The method was verified by considering various aspects of after aging mortar performance. This involves LOT-experiments by which the response of the mastic, the adhesion of the mastic to stone and the fatigue properties of the mastic and the stone-mastic adhesion zone are tested [4-6].

Finally LE2AP mortar, when mixed with reclaimed stone, should result in mixtures that in all known aspects are equal or better than freshly produced mixtures. If this is found true the Mix Design method would remain very simple in the sense that a LE2AP mixture should have the same (or very similar) composition as a freshly produced target mix.

To obtain a workable system the aim in LE2AP is to produce a standard LE2AP mortar containing a 20-25% “in” (m/m) bitumen 70/100. The mortar composition will be selected such that it may be used without alter for the production of PA (which contains a rich mortar). When this standard LE2AP mortar is used to produce various types of dense AC especially sand has to be added to the mixture to make the mortar poorer.

Following the previous the reader is invited to understand that the introduction of a rich standard LE2AP mortar will allow for the production of most of the mixtures containing non-modified bitumen produced by BAM. In some cases this may result in the additional application of small quantities of fresh bitumen. In many cases the standard mortar may be mixed with reclaimed stone to form a mixture. And, especially in the case of producing dense AC, sand needs to be added to the mix.

7.2. Viscous Fluid Design

As explained a high quality standard LE2AP mortar produced on basis of reclaimed mortar sand should be available as a new commodity in the near future. A starting point is that this mortar should have a constant bitumen content and that

the properties of that bitumen are constant and equal to that of a standard pen 70/100 pen bitumen, i.e. the workhorse bitumen in the Netherlands. The defined standard mortar may be used in the majority of Dutch mixtures and may ultimately replace the usage of pure bitumen in those mixtures.
In the production process of BAM a pen 40/60 and a pen 100/150 bitumen are available. A rejuvenator is also available. Since the percentage of bitumen in the mortar sand may vary, the amount of bitumen and rejuvenator that may be added to obtain a quality mortar with 70/100 pen bitumen will also vary. The amount of fresh bituminous products that may be added to the reclaimed mortar sand is determined as follows.

$$\boldsymbol{BB} = (\boldsymbol{CC} - \boldsymbol{AA})/(\mathbf{1} - \boldsymbol{CC}) \tag{1}$$

Where: AA=bitumen content in mortar sand (%"in") [-], BB=amount of fresh bituminous products to be added to mortar sand (%"on") [-], CC=amount of bitumen in standard mortar (%"in") [-].

To make matters worse the bitumen in the mortar sand may differ in terms of aging. Depending on the pen of the bitumen in the mortar sand an application rate for pen 40/60 bitumen (b), pen 100/150 bitumen (c) and rejuvenator (d) should be found such that the bitumen in the standard mortar will be equivalent to a standard 70/100 pen bitumen.

$$\mathbf{pen}\ {}^{\mathbf{70}}/_{\mathbf{100}} = \mathbf{a.old\ bit} + \mathbf{b.pen}\ {}^{\mathbf{40}}/_{\mathbf{60}} + \mathbf{c.pen}\ {}^{\mathbf{100}}/_{\mathbf{150}} + \mathbf{d.rejuv.} \tag{2}$$

And

$$\mathbf{b} + \mathbf{c} + \mathbf{d} = {}^{\mathbf{BB}}/_{(\mathbf{AA} + \mathbf{BB})} \quad \mathbf{and} \quad \mathbf{a} = {}^{\mathbf{AA}}/_{(\mathbf{AA} + \mathbf{BB})}$$

Where: a, b, c, d: Rate of application of old bitumen (via mortar sand), pen 40/60, pen 100/150 bitumen and rejuvenator respectively. 100%=a+b+c+d.

On the basis of phenomenological research a Viscous Fluid Design method was developed to ensure that the bitumen in the standard mortar always equals a pen 70/100 bitumen. The method demands that the pen of the bitumen in the mortar sand is measured and also demands that the pen of the virgin 40/60 bitumen and the pen of the virgin 100/150 bitumen are known. Independent of the rate of fresh materials to be added to the mortar sand the procedure that was developed is highly accurate ± 10 pen, see Figure 6. This implies that the standard mortar will not have a pen 70/100 bitumen such as used today, but a pen 75/95 bitumen. This accuracy is the first indication that the LE2AP process will result in high quality new asphalt.

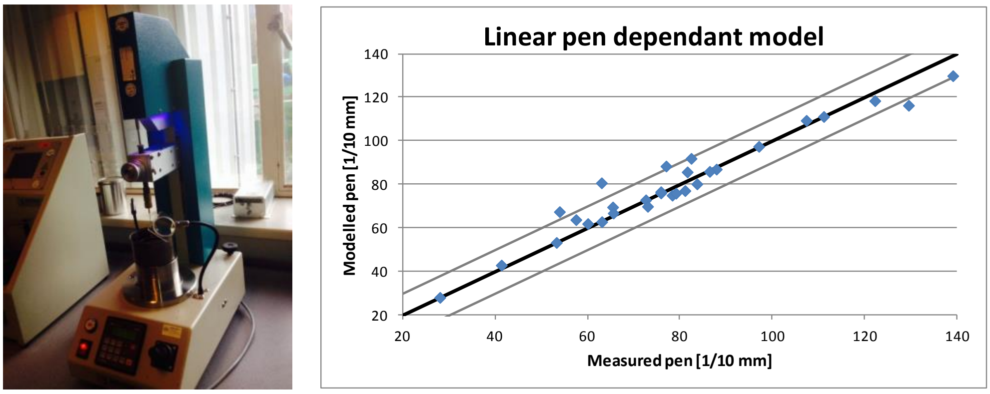

Figure 6: Left, pen measurement device at BAM laboratory. Right, the bitumen design procedure predicts the pen with an accuracy of ±10 pen

The Viscous Fluid Design method is based on a total of 28 data points and based on measured pen values only. It should be obvious that the pen-value may be an important indicator of bitumen quality, but it can certainly not be used as an indicator of mortar performance. For that reason research to come to a mortar design method further focuses on mortar performance.

7.3 Mortar Design

The Mortar Design method is derived on basis of the virgin response behaviour of LE2AP mortar in relation to the virgin response of a freshly produced equivalent mortar. For this purpose use is made of LOT DSR mortar response tests [5]. In these tests a 20 mm high mortar column with a 6 mm diameter is subjected to a sinusoidal load at a range of frequencies and temperatures. Results of these tests can be used to construct a mortar response master curve. Figure 7 gives an impression of the test.
Response tests were first done using the mortar of a Porous Asphalt, PA 11/16 with BAM mixture code TB075 as a reference. All tests were done on two separate samples. Through the combined data master curves of stiffness, G*, and phase lag, δ, are fitted with high accuracy, see Figure 8. Knowing that master curves are fitted with high accuracy, the obtained master curves are further analysed here. Tests that were done are listed in Table 1. The reference mortar

TB075 fresh is produced using fresh materials only and fully complies with the mix recipe of the selected PA mixture. Mortar TB075 0% is produced on basis of reclaimed mortar sand and similar to fresh mortar TB075. Using the Viscous Fluid Design the ingredients b, c and d are dosed such that both the bitumen content and the bitumen quality (pen) equal that of the fresh mortar. As indicated in Table 1 the composition of the solids in the this mortar differs from mortar TB075 fresh, i.e. mortar TB075 0% has a relatively high percentage of sand and as a result a relatively low percentage of filler dust. These differences follow from the fact that the mineral composition of the reclaimed mortar sand, which is the basis for the LE2AP mortar, differs from that of a freshly produced mortar. These differences in mineral composition can be fully corrected so that mortar TB075 100% is obtained. Similarly the composition of solids may also be partially corrected so obtaining the mortars TB075 25%, TB075 50% and TB075 75%.

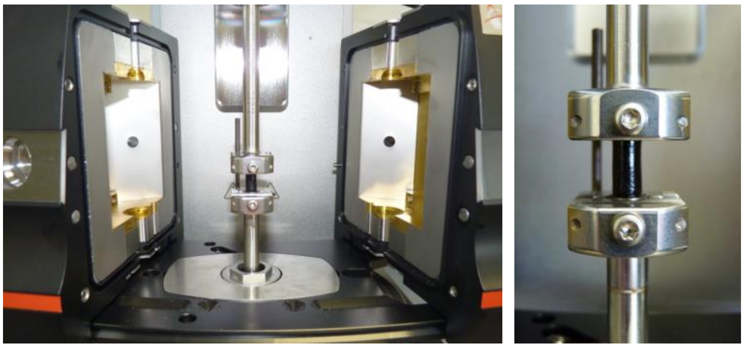

Figure 7: Response test on mortar columns. Left: detail of DSR at BAM laboratory with mortar column mounted in machine. Right: a mortar column clamped into the DSR

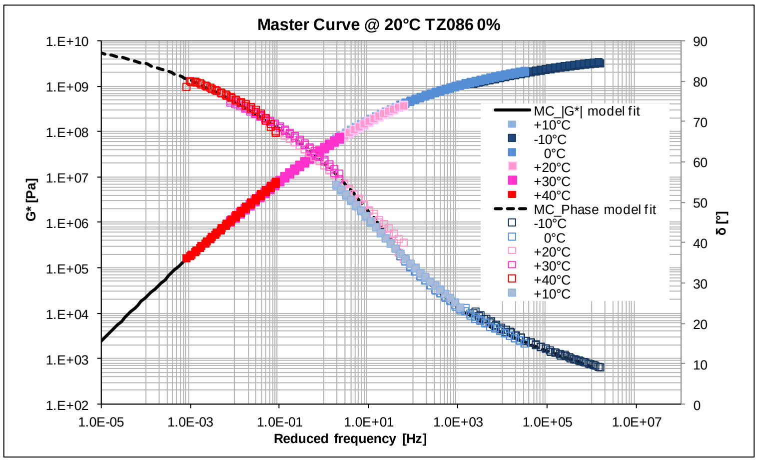

Figure 8: Representative plot of data versus fitted Master Curves. Each set of data considers two tests on two individual specimens

Table 1: Mortars tested of which the response behaviour was tested

		Mortar code	Sand ≥ 0.5 mm	Sand < 0.5 mm	Filler < 63 μm	Bitumen 70/100
Mortars based on TB075 PA 11/16	Treated RC mortar	TB075 0%	23%	30%	17%	30%
	Treated RC mortar	TB075 25%	24%	26%	20%	30%
	Treated RC mortar	TB075 50%	25%	22%	23%	30%
	Treated RC mortar	TB075 75%	25%	20%	25%	30%
	Treated RC mortar	TB075 100%	26%	18%	27%	30%
	Fresh mortar	TB075 fresh	26%	18%	27%	30%
Mortars based on TZ086 PA 0/16	Treated RC mortar	TZ086 0%	25%	32%	18%	26%
	Treated RC mortar	TZ086 100% f	23%	29%	22%	26%
	Treated RC mortar	TZ086 100%	32%	21%	22%	26%
	Fresh mortar	TZ086 fresh	32%	21%	22%	26%

Correction, however, implies that fresh solids have to be added to the mortar mix. This implies that fresh bitumen has to be added also to maintain the desired bitumen content. Compensation of the solids thus reduces the percentage of recycling in the mortar on basis of reclaimed mortar sand.

Figure 9 presents the results of the LOT mortar response tests. As indicated the difference between the various mortars produced on basis of reclaimed mortar sand is negligible. This indicates that correction of the solid composition has no effect on mortar response. It is furthermore shown that mortar TB075 fresh is slightly softer than the mortars produced on basis of reclaimed mortar sand at low frequencies, i.e. lower G* and higher δ.

The results plotted in Figure 9 astonished the LE2AP team because it was expected that correction of the composition of solids in the mortar would show in obtained results. It was therefore decided to deviate from the research plan and execute additional tests on a PA mortar having a lower bitumen content. This was done since it was expected that the effects of solids on response will increase as the bitumen percentage decreases. For these additional tests the mortar of PA 0/16 TZ086 was used as a starting point. Apart from the fresh mortar, TZ086 fresh, three mortars on basis of reclaimed mortar sand were tested. Similar to the initial tests a mortar TZ086 0% and a mortar TZ086 100% were made on basis of reclaimed mortar sand. In addition to this mortar TZ086 100% f was made on basis of reclaimed mortar sand. In this mortar the bitumen/filler ratio was 100% corrected.

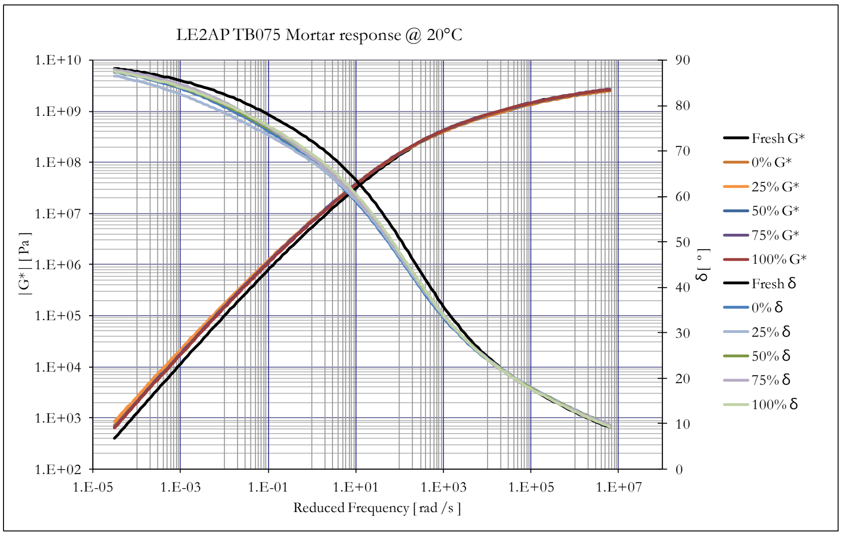

Figure 9: Response characteristics of mortar TB075 produced on basis of fresh materials and various equivalents produced on basis of reclaimed mortar dust

Astonishing enough results of these additional tests confirmed the observations of the first tests, see Figure 10. Again it was observed that correction of the mineral fraction does not affect mortar response behaviour and also it is again observed that the fresh mortar is slightly softer at low frequencies, i.e. lower G* and higher δ.

On the basis of discussed results it was concluded that the response behaviour of PA mortar containing high quantities of bitumen is dominated by the bitumen properties. This indicates that the discussed mortar response tests can also be considered as a thorough validation of the Viscous Fluid Design method. Given obtained results it was consequently concluded that the available Viscous Fluid mix Design method leads to a bitumen that is slightly harder than the target bitumen. It is expected that this is a result of the extraction process used to obtain old bitumen from reclaimed mortar sand. To compensate for this a few additional tests that are beyond the scope of this paper were performed on mortar. These tests indicated that almost full agreement between virgin mortar on basis of reclaimed mortar sand and fresh PA mortar is obtained when the target pen in the Viscous Fluid Design method is increased by 8 pen.

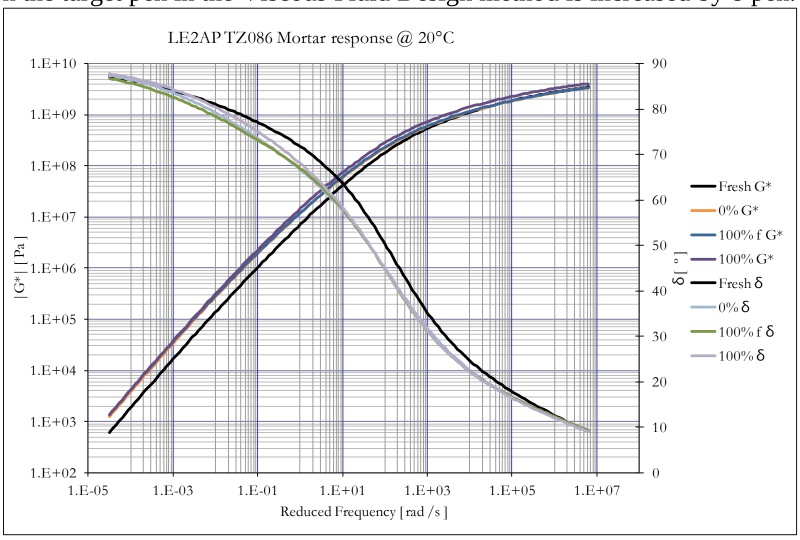

Figure 10: Response characteristics of mortar TZ085 produced on basis of fresh materials and various equivalents produced on basis of reclaimed mortar dust

7.4 Mortar performance after aging

As the purpose of LE2AP is to come to high-quality horizontal recycling, focus should not be so much on the performance of virgin mortar on basis of reclaimed mortar sand as discussed in Section 7.3. This is because it is known from theory and practise that virgin surface layers produced from fresh materials show good performance in all cases. It is after aging that differences in performance become obvious. For this reason it is believed that the characteristics of aged mortar are indicative of performance in practise.
Tests to indicate the performance of LE2AP mortar on basis of mortar sand after aging were done to validate the Mortar Design method. The mortars listed in Table 2 are considered initially.

Table 2: Mortars considered in the after aging performance tests

	Mortar code	Sand 0.5-2 mm	Sand 0.063-0.5 mm	less than 0.063 mm	Bitumen 70/100
Mortars based on TZ086 PA 0/16	TZ086 0%	25%	32%	18%	26%
	TZ086 100% f	23%	29%	22%	26%
	TZ086 150% f	21%	27%	26%	26%
	TZ086 100% frr	23%	29%	22%	26%
	TZ086 fresh	32%	21%	22%	26%

The mortars TZ086 fresh, 0% and 100% f equal those as listed in Table 1. It is expected that the aging behaviour of mortar is dependant on the interaction between bitumen and filler. This is because the huge specific surface of the filler fraction. For this reason mortar TZ086 150% f is considered in the test program. This particular mortar on basis of mortar sand contains additional filler, i.e. compensation of filler content 150%. Mortar TZ086 frr is also considered. This particular mortar on basis of reclaimed mortar sand is made with a reduced dosage of rejuvenator (component d), as a result this mortar contains an ultimately high amount of soft bitumen 100/150 (component c). It is stated explicitly that the Viscous Fluid Design method indicates that all mortars listed in Table 2 should have the same bitumen in terms of pen-value.
The mortars listed in Table 2 are aged according to the method proposed in [7]. Mortar slabs with 2 mm thickness were hereto placed in a stove at 135°C for 44 hours. It is expected that the aging that is obtained in this manner is equivalent to 7 years of aging of porous surfacing in the Netherlands [7].
The planned after aging performance tests consider mortar response, mortar cohesive fatigue both measured by means of the DSR using LOT procedures [5]. Results of the response tests are shown in Figure 11 which presents the complex stiffness of the mortars in Table 2 before and after aging. The presented master curves were made for a reference temperature of -10°C. This is because a lot of knowledge is available at BAM about the relation between PA performance in practise and mortar response behaviour at -10°C [8]. The master curves are plotted for the frequency window from 1e-5 to 10 Hz, which is the frequency range in which mortar response is indicative of PA performance in practice.
Figure 11 clearly indicates two clusters of lines. One cluster contains the response behaviour of virgin mortars whereas the second cluster indicates the response behaviour after aging. Within both clusters differences between the various mortars seem relatively small and perhaps even irrelevant. For this reason the aging index, which is defined as the ratio between the G* before and after aging, was defined. Figure 12 presents the aging index for the various mortars involved in the tests.

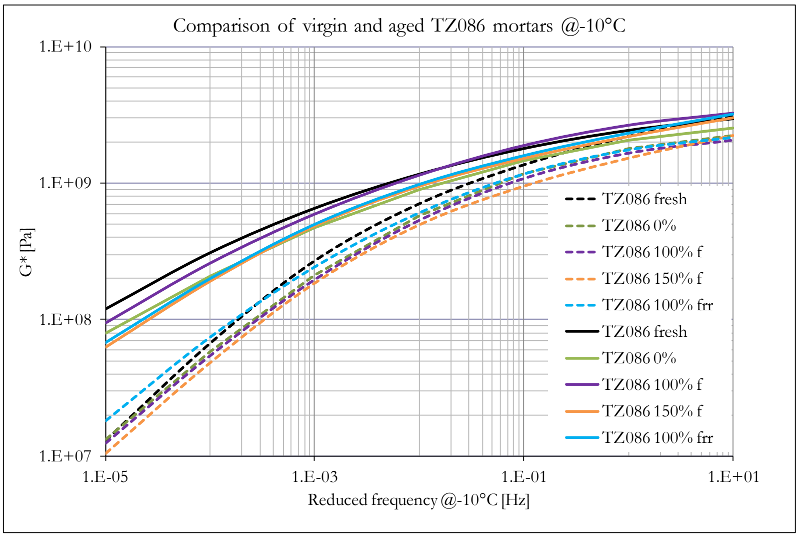

Figure 11: Response characteristics of various mortars TZ086 produced on basis of fresh materials and various equivalents produced on basis of reclaimed mortar dust before and after aging

The aging index indicates that mortar TZ086 fresh hardens the most at low frequencies whereas the hardening due to aging at higher frequencies is amongst the lowest of involved mortars. Since the behaviour at low frequencies is especially important with respect to winter ravelling in PA surfacing layers this is a strong indication that mortar on basis of reclaimed mortar sand might outperform fresh mortars when applied in PA. It is also shown that mortar TZ086 100% frr has the best overall aging behaviour.

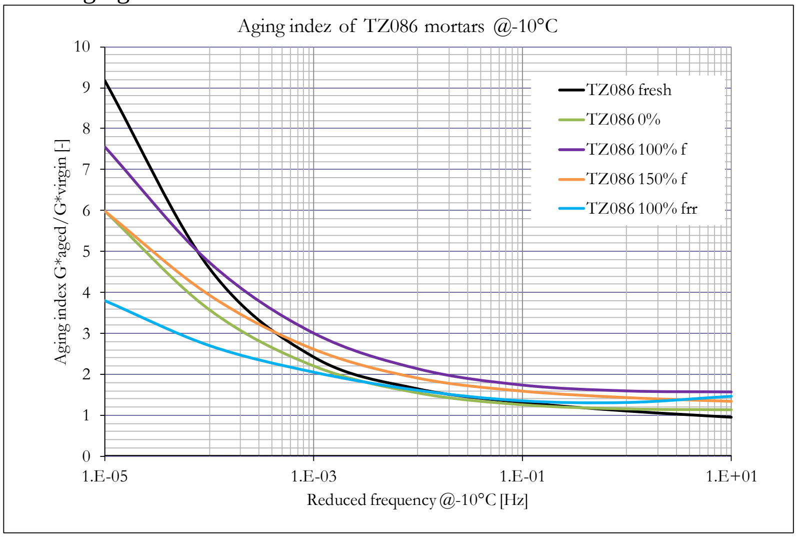

Figure 12: Aging index of mortar TZ085 produced on basis of fresh materials and various equivalents produced on basis of reclaimed mortar sand

For the mortars TZ086 fresh, TZ086 0% and TZ086 100% f the after aging fatigue resistance was determined. The fatigue tests were done at 10°C and in strain controlled mode. In the tests a sinusoidal loading at 30 Hz was applied. Results are visualised in Figure 13. Figure 13 clearly indicates that the TZ086 mortars produced on basis of reclaimed mortar sand outperform the freshly produced TZ086 mortar.

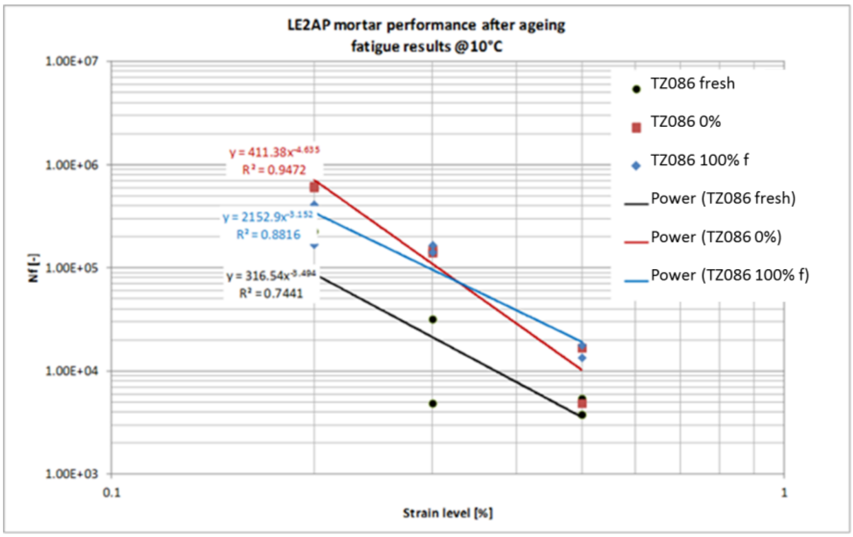

Figure 13: After aging fatigue performance of mortar TZ086 produced on basis of fresh materials and two equivalents produced on basis of reclaimed mortar sand

7.5 Conclusions

On the basis of discussed work the following is concluded.

A Viscous Fluid Design method is available. The method works as follows:

1. Determine the pen of the old bitumen in the reclaimed mortar
2. Set a target pen and increase this value with 8 pen.
3. Given the amount of viscous fluids to be added (b+c+d) determine the application rates of components b, c and d such that the target pen is obtained.

A Mortar Design method is available. This method remains surprisingly simple and works as follows:

1. Determine the percentage of bitumen in the reclaimed mortar sand.

2. Set a target bitumen content for the standard LE2AP mortar.
3. Determine the summed application rate of fresh viscous fluids to be added to the reclaimed mortar sand (b+c+d) and use this as input for the Viscous Fluid Design method.

8. MIXTURE DESIGN

In the previous sections it was shown that the LE2AP recycling process guarantees that a high quality mortar can be produced on basis of reclaimed mortar. This LE2AP mortar consists of a 70/100 pen bitumen that in terms of quality (pen and aging susceptibility) at least equals a fresh bitumen. When the bitumen content of LE2AP mortar is made equal to that of a target mortar the properties of the obtained LE2AP mortar are at least equal to that of the target mortar; response behaviour (master curve of G* and δ), fatigue behaviour, aging susceptibility.
In the LE2AP philosophy (striving for equivalence at the scale of bitumen, mortar and bulk) this leads to the conclusion that a mixture in which LE2AP mortar is applied should have properties that at least equal those of a freshly produce mixture provided that the composition of the two mixtures are equal in terms of mineral grading (>2 mm) and mortar content (V/V).

Table 3: Summarised mixture recipes, production methods and ITSR values for variants of mixture TZ086

	TZ086 Type Test	LE2AP 0% RC stone	LE2AP 50% RC stone	LE2AP 95% RC stone	LE2AP 95% RC stone LTA
Morene crushsand [%]	9.14%	-	-	-	-
wigro 60k factory filler [%]	3.05%	0.48%	0.48%	0.48%	0.48%
Baghouse dust [%]	1.0%	-	-	-	-
Bestone 11/16 [%]	21.1%	21.1%	10.5%	-	-
Bestone 8/11 [%]	36.4%	36.4%	14.3%	-	-
Bestone 4/8 [%]	24.9%	24.9%	16.2%	4.3%	4.3%
LE2AP standard mortar [%]	-	17.1%	15.8%	14.8%	14.8%
RC stone 5/8 [%]	-	-	12.5%	23.1%	23.1%
RC stone 8/16 [%]	-	-	30.0%	57.3%	57.3%
70/100 bitumen [%]	4.4%	-	-	-	-
Recycling percentage [%]	0.0%	14.2%	55.7%	92.7%	92.7%
LE2AP mortar mixing temperature	-	170°C	170°C	170°C	170°C
Mineral mixing temperature	170°C	170°C	170°C	170°C	120°C
Void ratio [%]	20.5%	19.8%	20.8%	20.8%	20.4%
ITSR [%]	88%	96%	93%	100%	91%

The previous assumption was validated and found to be true with respect to mortar adhesion and the resulting moisture sensitivity as tested by means of ITSR tests as per NEN-EN 12697-12. Test were done on TZ086 mixtures consisting of LE2AP mortar mixed with various rates of reclaimed stone, RC stone, see Table 3. As shown by Table 3 all LE2AP variants outperform the reference TZ086 mixture in terms of ITSR.

9. SEMI FULL-SCALE MORTAR PRODUCTION

From previous testing it was learned that LE2AP mortar has a yoghurt like consistency at 165-170°C. To produce larger quantities of LE2AP mortar and so proceed into the production of test slabs for further testing and to evaluate whether full-scale production of LE2AP mortar is feasible a production unit was designed and built. The unit was designed such that it may be extended into a production and foaming unit after it is proven that the unit is capable in heating, mixing and pumping LE2AP mortar. The production unit consists of a heated drum that may contain 60 kg of LE2AP mortar. A stirring device is mounted in that drum so that the heated mortar is stirred and homogenised continuously. A mortar pump is installed on the unit. Initially this pump just helps to circulate the mortar, see Figure 14. In the second stage, when a foaming device is added to the mortar production unit, the pump is used to pressurize the mortar so that it may be foamed. It was found that, after some minor childhood diseases, the mortar production unit functioned flawlessly.

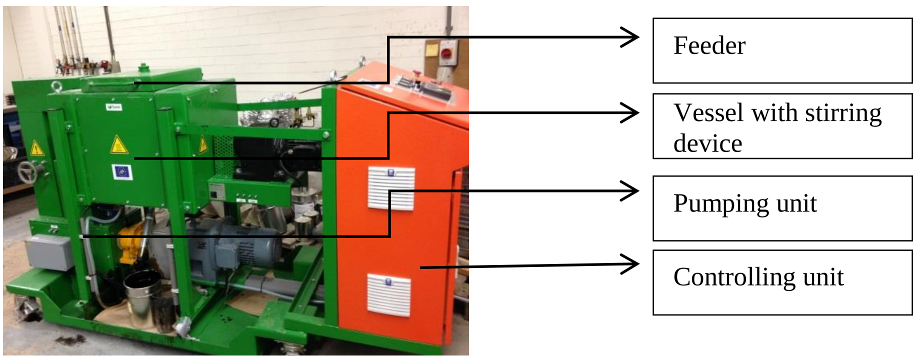

Figure 14: The mortar production unit in its 1st phase, i.e. without a mortar foaming device

The mortar production unit was used to produce the mortar for four test slabs of PA containing 93% of recycling, see the latter two columns of Table 3. Figure 15 gives some idea about the production of the test slabs.

Figure 15: Visual impression of the semi full-scale plate production

10. SURFACE CHARACTERISTICS

In the Netherlands approximately 90% of the primary road network has some type of PA surfacing. In most cases ravelling, i.e. the loss of stone from the road surface, is limiting the service life of PA. However, skid resistance is also an important issue and may in cases limit the service life. It is for these reasons that the ravelling resistance and the skid resistance of the LE2AP TZ086 mixtures with 93% recycling are tested.

From earlier research it is known that the ravelling resistance of PA is directly related to the mechanical behaviour of aged mastic. Therefore the tests slabs were first aged by placing the slabs in a stove at 135°C for 44 hours (7). After aging the ravelling resistance of the LE2AP TZ086 mixtures was determined by use of the Aachen Ravelling Tester, ARTe .

Since indications are that LE2AP mortar outperforms fresh mortar it was expected that the ARTe test would indicate good ravelling resistance. The ARTe proved that this expectation is true both on basis of the mass of material lost during the ARTe test and on the basis of before and after surface scans which are beyond the scope of this paper. Figure 16 presents the results of the ARTe tests and relates results to some freshly produced types of PA.

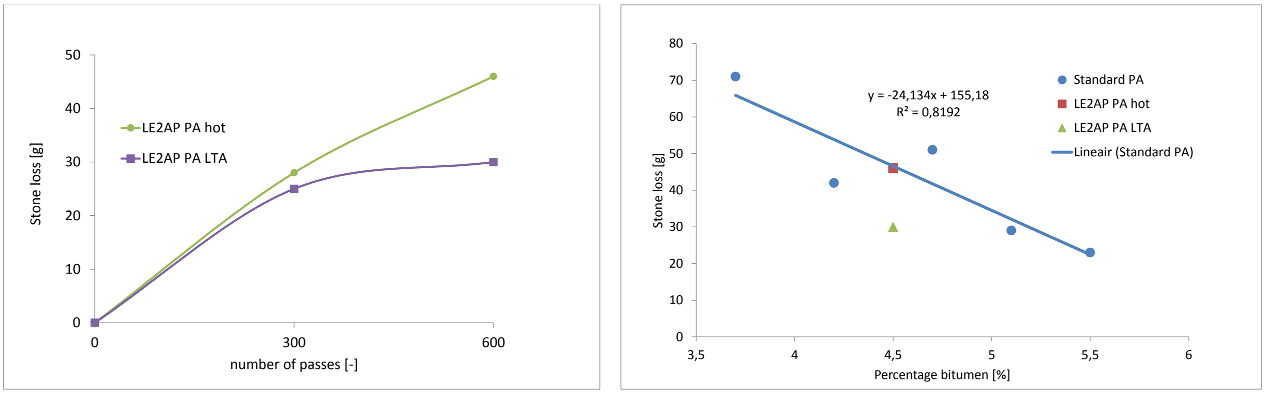

Figure 16: Results of the ARTe test on the TZ086 LE2AP 95% RC stone mixtures. Left: Material loss over. Right: Results relative to freshly produced types of PA as a function of mixture bitumen content.

In the ARTe ravelling test friction is applied to the test slabs via a full scale tyre. As a result the bitumen coating of the surface stones is abraded and the surface of the test slabs is polished. By use of the Skid Resistance Tester, SRT, the skid resistance of the test plates was measured and compared to freshly produced PA. Results are shown in Figure 17 in which results for PA applied on the A4 and A18 are shown as reference values.

The previous indicates that the surface characteristics (ravelling resistance and skid resistance) of LE2AP PA containing 93% of reclaimed material are fully equivalent to those of freshly produced PA.

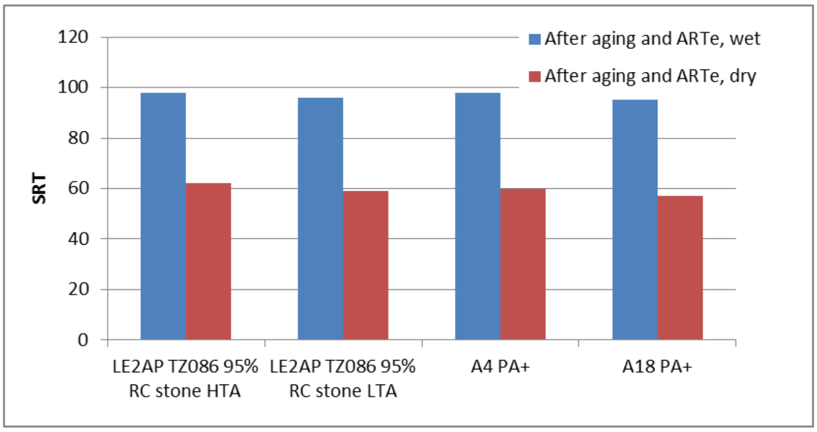

Figure 17: After aging and ARTe SRT of LE2AP TZ086 mixtures in relation to PA applied on Dutch motorways

11. FUTURE WORK

LE2AP is an ongoing project. The following steps are made in the near future.

- Incorporating a mortar foaming device on the laboratory mortar production unit. The quality of LE2AP mixtures produced at low temperatures will then be tested by use of that device.
- Execution of a full-scale test in which 300 m^2 of warm produced LE2AP PA is installed one the site of one of BAM's asphalt plants. Hereto an existing plant is equipped with temporary machinery to allow for the full scale production of LE2AP asphalt.
- On the basis of the full-scale test decisions are made on how to incorporate LE2AP technology in asphalt plants. The main issue is the production and foaming of mortar, however, also dryer drums are given attention.
- LE2AP technology is incorporated into one of BAM's asphalt plants to allow for large scale production of LE2AP asphalt.
- Using this plant the LE2AP PA required to pave 1 km of road is produced. To meet with set requirements the following strategy is followed.
  1. Obtaining >7 dB initial noise reduction requires that a two layer PA surface is installed. To ensure that the 7 dB goal will be achieved the surfacing system will be acoustically designed by a third party.
  2. To achieve >80% recycling the lower layer of this surfacing system will consist of both reclaimed mortar and reclaimed stone. The recycling percentage of this layer will be >90%. The upper layer will consist of RC stone combined with a fresh polymer modified mortar. As a result this layer will contain >80% of recycled material. Combined the surface layer will have far more than the required 80% recycling.
  3. Production of the materials should be done at <80°C. This remains a true challenge. However, BAM has elaborate knowledge when it comes to the production of LTA. This knowledge was acquired during the development of BAM's LEAB system which allows for the production of LTA by use of high end foaming technology [10]. Using LEAB technology BAM has produced high quality fresh PA at temperatures of 100°C. LEAB knowledge and experience is applied in the LE2AP project to foam mortar and to lower production temperatures.
  4. As per LIFE+ subsidy the emissions that follow from asphalt production have to be reduced significantly. Achieving this goal is a direct result of the LE2AP process. A) reclaimed mortar does no longer pas trough a dryer drum and thus does not come into contact with the burner flame. B) lowering the production temperature will further reduce emissions.

12. DISCUSSION AND CONCLUSIONS

In this paper a new approach to asphalt recycling was discussed. Insight into an ongoing research into the development of a desired recycling procedure was given. Key issues of the new approach of asphalt recycling are the following:

- Old asphalt is milled off using as little water as possible and thereafter kept dry to limit the moisture content of reclaimed asphalt.
- The reclaimed asphalt is decomposed to obtain reclaimed stone >2 mm containing very limited amounts of bitumen and a mortar sand <2 mm containing a high percentage of bitumen.
- The mortar sand is heated to 165-170°C, homogenised and treated so that a standard mortar with constant bitumen content and performance is obtained.
- The standard mortar is produced in an enclosed tank fitted with a stirring device and thus is not brought into contact with a dryer drum burner flame or air. This limits emissions and prevents burning and aging of bitumen.
- The standard mortar with constant performance characteristics and bitumen content may be used to produce most PA mixtures in use today. The production of denser mixtures requires that especially sand is added in the mixer.
- The standard mortar is foamed and brought into the mixer where it is mixed with heated (80°C) reclaimed stone. Due to asphalt decomposition there is full control over the mixture's composition (recipe control).

- Within the LE2AP project use is still made of production plants. However, the ultimate goal is to mix the foamed mortar with reclaimed stone that is not or only partially heated. This would allow for on-site high-quality cold recycling.

Although the discussed LE2AP project is on-going the following conclusions can be drawn.

- True dry milling does not seem feasible today. However, it is feasible to reduce the water injection by 25% to 0.75%. Tests to see whether further reduction is possible are ongoing.
- Decomposition of reclaimed asphalt is definitely feasible. BAM has a working decomposition unit in use.
- A Viscous Fluid Design method and a Mortar Design method were developed. Using these procedures a high quality standard mortar can be produced on basis of reclaimed mortar sand.
- It was found that the bitumen content of the standard mortar is of influence on mortar performance. The effects of the composition of the solid fraction in this mortar on performance remains negligible. It is expected that this is due to the high bitumen content of tested PA mortars.
- It can be guaranteed that the standard mortar will always contain a pen 85/95 bitumen irrespective of the bitumen content and bitumen quality (pen) of the bitumen in the reclaimed mortar sand. Due to the production process of this mortar a homogeneous mortar is obtained.
- Strong indications are that LE2AP mortar might outperform fresh mortars. The latter is because of two reasons.
  1. The Viscous Fluid Design method provides more control over bitumen pen that current day specification. A fresh pen 70/100 bitumen versus a reclaimed pen 85/95 bitumen.
  2. The aging performance of the standard LE2AP mortar is better than that of a fresh mortar.
- LE2AP PA mixtures containing up to 93% recycling were produced at semi full-scale. These mixtures were at least equivalent to their freshly produced peers.
- The effects of mortar foaming on mix quality remain unknown. However it is already known that without foaming of mortar high quality mixtures may be produced at reduced temperatures.

ACKNOWLEDGEMENTS

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PATENTS

The LE2AP approach of asphalt recycling is protected by various patents.

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