Towards sustainable horizontal asphalt recycling

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ABSTRACT: The growing needs for sustainability demand that all asphalt concrete layers in an asphalt structure can be produced with high quality, low production temperature and using high percentages of reclaimed material. By using LEAB bitumen foaming technology, binder/base layer asphalt mixtures containing up to 60% reclaimed material can be produced at about 110°C with good performance. The lowered production temperature results in 25% reduction of CO_2 emission and 40% reduction in energy. With the support of the European LIFE+ program it is shown that a prous asphalt layer can also be recycled horizontally. The reclaimed porous asphalt is first decomposed into reclaimed stone and reclaimed mortar. By rejuvenating and foaming of the reclaimed mortar, and mixing with the reclaimed stone, porous asphalt is designed containing more than 90% recycled material and produced at around 110°C. This porous asphalt is proven to be identical as the hot mix in terms of mortar and mixture performances.

1 INTRODUCTION

With the growing concerns of government bodies on climate change and, the historic Paris Agreement on Climate Change has been signed sustainability on 12 December 2015 by 195 nations. The agreement aims to keep the global temperature rise in this century below 2°C and even striking to 1.5°C. As a result, sustainable technologies enabling the high quality recycling of asphalt pavements are more and more popular in the Netherlands and all over the world. The Netherlands is one of the most active countries in asphalt recycling. In the Netherlands, a typical asphalt pavement structure on the Dutch motorway system consists a porous asphalt (PA) surface layer placed over a dense binder and base layer. During renovation activities, a large amount of reclaimed asphalt pavement is obtained and reused. According to the European Asphalt Pavement Association, the Netherlands produces 9.3 million tons of asphalt and 4.5 million tons of Reclaimed Asphalt (RA) every year (EAPA 2013). And about 80% of the available RA is re-used in new asphalt production. However, most of the asphalt recycling is downgrade recycling. For example, the reclaimed porous asphalt RA is commonly not reused in constructing new asphalt mixtures, although research indicates that a maximum of 30% of porous asphalt RA may be used in the production of these layers. In binder and base layer asphalt mixtures, the RA can be used as an ingredient. Practically, 60% RA is used with success without extra addition of rejuvenators. Attempts with higher percentage recycling up to 100% together with rejuvenators give also promising results. From the point of view of social and economic needs, recycling horizontally is necessary. Horizontal recycling means that the recycled surface layers such as porous asphalt, SMA etc. to be reused as newly produced porous asphalt and SMA. And the recycled binder/base layers to be reused as newly produced binder/base layers. And no asphalt is to be recycled as base or subbase.

On the other hand, the application of the warm mix technology is also getting more attention due to its economic and social-environmental benefits (D'Angelo 2008). The principle of the using foamed bitumen was developed in the 1950s (Csanyi 1957). When hot bitumen and water meet each other, a large expansion in volume can be expected at a temperature around 100-110°C. This allows the binders to effectively coat the warm mineral aggregates and to produce a half-warm/warm asphalt mixture at a temperature around 90-110°C (D'Angelo et al 2008; Jenkins 2010).

As a result, this paper discusses the possibilities of high-quality high-percentage recycling of a motorway asphalt structure by the use of foaming technologies. The total asphalt structure will be horizontally reconstructed at a temperature of 110°C. The percentage of recycling for binder/base layer is about 60% and the percentage of recycling for porous asphalt layer is above 90%!

2 SUSTAINABLE RECYCLING OF BINDER/BASE LAYER ASPHALT MIXTURES

2.1 *Introduction*

As shown in Figure 1, the basic principle of the LEAB technology is to produce asphalt mixtures using with the foam technology. The LEAB (Dutch acronym for Low Energy Asphalt Concrete) technology, which was developed by BAM, has been successfully applied in practices for more than 10 years (Jacobs et al 2010). Until now, more than 400000 ton LEAB asphalt mixtures have been produced in about 200 road construction projects including motorways, provincial roads and streets. LEAB production facilities are installed in 4 asphalt plants in the Netherlands. The LEAB mixtures produced at 90-110°C have the same composition and performance characteristics as their hot mix equivalents produced around 150-170°C. In this paper, the LEAB technology is used to produce a high quality bin/base asphalt layer containing 60% RA.

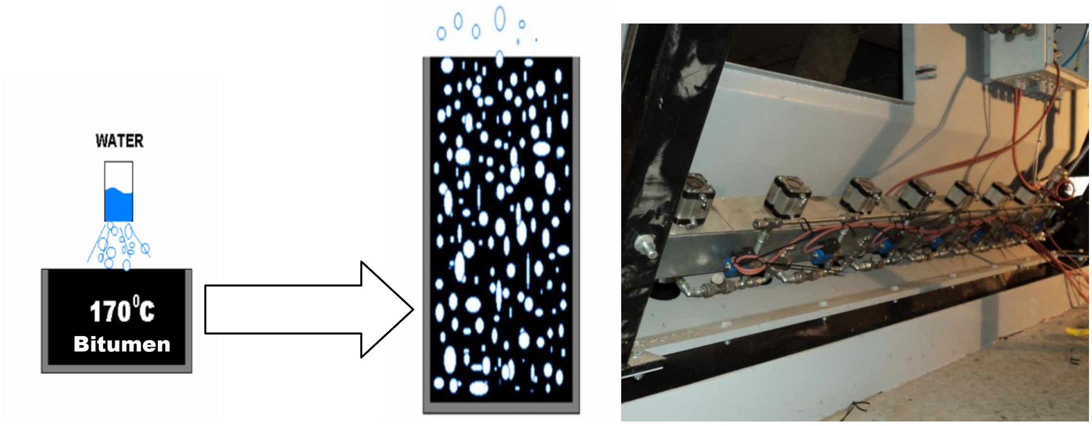

Figure 1 Principle of bitumen foaming and LEAB foaming installations in the asphalt plant (Jacobs et al 2010)

2.2 *Materials*

Table 1 gives an overview of the materials used in the tests. There are three types of binder/base asphalt mixtures described namely, LEAB 22 bin/base with 60% RA, AC bin/base with 60% RA and AC 22 bin/base without RA, respectively. It is observed that the LEAB 22 with 60% RA has identical compositions as its hot variant AC 22 bin/base with 60% RA. The reclaimed asphalt 0/20 fraction has a bitumen content of 5.0% and a bitumen penetration of 22 (0.1mm). In order to balance the total penetration of the mixtures, a 70/100 bitumen with a penetration value of 75 (0.1 mm) was used for mixtures containing 60% RA. The mixtures AC 22 bin/base with 60% RA and AC 22 bin/base without RA were produced at around 165°C, and the mixtures LEAB 22 bin/base with 60% RA were produced at around 110 °C.

Table 1. Overview of materials and receipts used for binder/base layer asphalt mixtures

	LEAB 22 bin/base 60% RA	*AC 22 bin/base 60% RA*	*AC 22 bin/base*
Limestone 6/10 [%]	5.2	5.2	27.0
Limestone 10/14 [%]	6.3	6.3	8.6
Limestone 14/20 [%]	14.4	14.4	19.0
Natural sand 0/2 [%]	12.0	12.0	34.6
Factory produced Filler [%]	0.2	0.2	5.3
Baghouse dust [%]	0.6	0.6	1.0
Reclaimed asphalt 0/20 [%]	60.0	60.0	-
Bitumen 70/100 [%]	1.3	1.3	-
Bitumen 40/60 [%]	-	-	4.6
Percentage recycling materials [%]	60	60	0
Total bitumen content [%]	4.3	4.3	4.6
Production Temperature [°C]	105	165	165

2.3 *Bitumen Foaming*

The only extra component in LEAB was the use of an additive, which neutralizes the existing anti-foaming additive in the bitumen. The anti-foaming agent is necessary according to the bitumen producer to limit foaming incidences during transporting and pumping process. The addition of the additive is less than 0.2% of the foamed bitumen.

Figure 2 gives a typical result of the foaming properties of the LEAB bitumen in comparison with the standard penetration bitumen. With the addition of the additive, the expansion ratio increases slightly and the half-life of the foamed bitumen extends from 20 seconds to more than 3 minutes. It is known, although not shown in this paper for reasons of brevity, that a longer half time guarantees a longer time window between production and compaction. This ensures that LEAB asphalt mixtures are obtained in the field having the same performance characteristics as a hot mix directly after compaction with no curing time needed (Jacobs 2010).

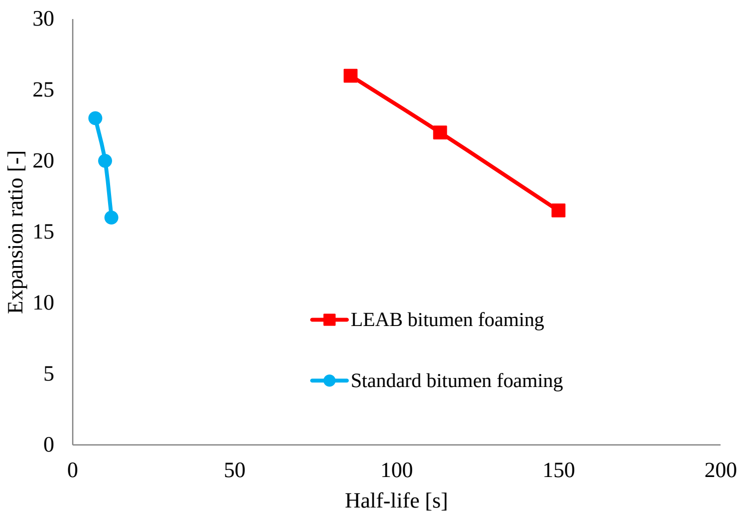

Figure 2 Results of foaming properties of LEAB bitumen

2.4 *Mixture Performance*

To evaluate the mixture performance, series of experimental investigations were carried out, including volumetric properties, water sensitivity, permanent deformation resistance and stiffness and fatigue properties. The obtained results lead to the same conclusion that the LEAB mixture is comparable with its hot variant. In this paper, some results of the stiffness modulus and fatigue resistance are shown. The stiffness modulus and fatigue properties of the mixtures are determined using the four point bending test (4PB) according to Annex B of EN 12697-26. To determine the stiffness modulus, specimens were tested at 20°C and various frequencies (between 0.1 and 30 Hz). The displacement controlled fatigue tests were conducted according to Annex D of EN 12697-24 at 20°C and 30 Hz.

Figure 3 gives the results of the stiffness and fatigue tests. It is shown that the mixture produced using a hot recycling method increases the stiffness of the mixtures. The equivalent mixture produced using LEAB technology does not show this increase in stiffness. This is mainly due to reduced aging of bitumen during mixture production process, where a lower production temperature is used. Another possible reason would be the non-optimal mixing between the aged binder and the foamed bitumen due to low production temperatures, which results in a low stiffness layered system. The fatigue performances of all three mixtures are almost identical. Based on the results of all the mechanical tests it can be concluded that the functional properties of the warm LEAB mix are comparable to the equivalent hot mix asphalt. The test results were also verified by several road authorities in the Netherlands. As a result, it is concluded that binder/base layers may be horizontally recycled using low temperature technology.

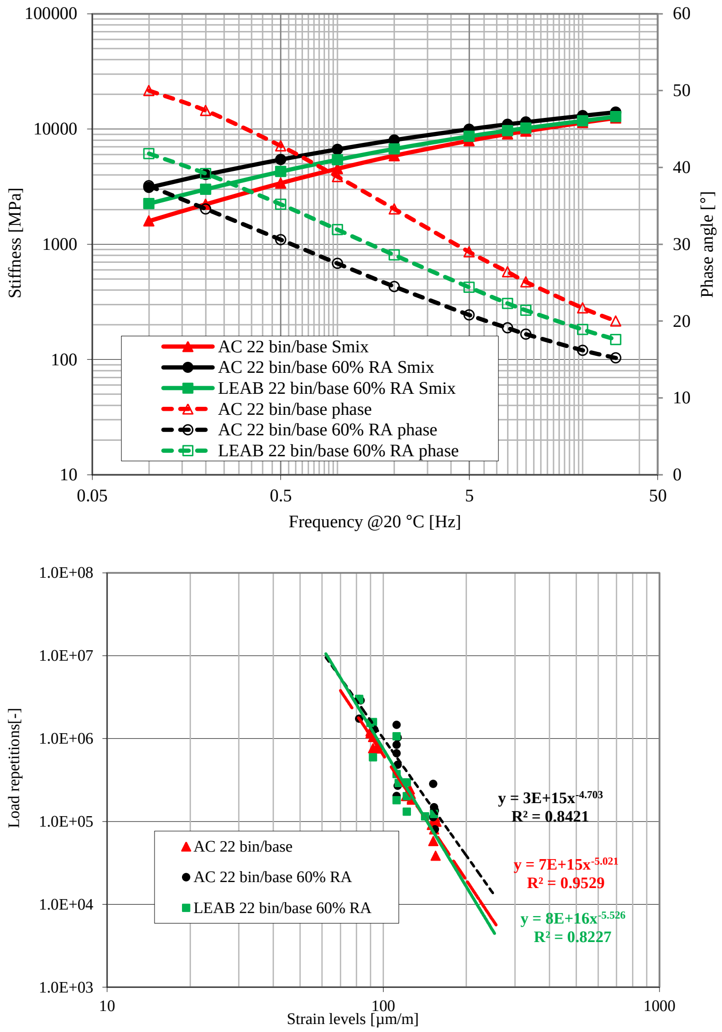

Figure 3 Results of stiffness and fatigue tests

3 SUSTAINABLE RECYCLING OF POROUS ASPHALT

3.1 *Introduction*

Porous asphalt is being applied as a surface layer on the Dutch motorway system since the early 1980’s. Application of porous asphalt concrete on the primary road network is mandatory and as a result approximately 90% of this network has a porous asphalt surface layer. This type of asphalt, which has an air void percentage around 20%, has great advantages with respect to noise reduction and reducing splash-spray, etc. However, due to its high void ratio porous asphalt can only perform when it is of highest quality. This implies that porous asphalt can only be produced when there is full control over mix composition and the quality of used ingredients. Because of this conventional recycling of this mixture is not feasible. It is thus of importance to develop a new horizontal recycling approach for porous asphalt surface layers.

In 2013, under a grant of the European Life+ program, BAM proposed an innovative way of horizontal recycling of porous asphalt. Under the project named “Low Emission2 Asphalt Pavement (LE2AP)”, a 1 km porous asphalt layer will be constructed containing more than 80% of recycling material and produced as a warm mix (Huurman 2015). As a result, this project will realize three goals; lowering CO_2-emissions, increase the rate of recycling and reducing noise.

In the LE2AP approach, the reclaimed porous asphalt passes through a rotary decomposition device and is separated into reclaimed aggregates with a small amount of bitumen and a bitumen-rich mortar fraction. The rotary decomposition device is a machine that uses the glassy behavior of asphalt mixtures at high frequencies. In the decomposition process, the milled off asphalt is thrown against a steel wall with certain speed, which results in extremely high load frequencies. At these frequencies, the bitumen and mortar show glass-like behavior at impact and brittle failure occurs. This results in the peeling off of the mortar film that surrounds individual aggregates. The reclaimed aggregates, called PA-stone, can be reused as high quality aggregates without further treatment. The reclaimed mortar is first treated and homogenized before it is reused as mortar for a new mixture. With a special foaming technology, the renewed mortar is foamed and mixed with the well-fractionized PA-stone. As a result, high quality warm produced porous asphalt containing a high percentage of reclaimed material can be produced.

3.2 *Materials*

Figure 4 and Table 2 illustrate the materials obtained after the rotary decomposition process. The bitumen-rich mortar contains about 10.5% bitumen and the reclaimed aggregates contain about 1% bitumen.

Table 3 gives the recipe of the LE2AP mortar and its fresh equivalent. The mortar contains sand, filler and bitumen, which is the binding agent of the porous asphalt. For this reason it is of great importance that the LE2AP mortar, produced on basis of reclaimed mortar, has the same characteristics as a freshly produced mortar. The LE2PA mortar is designed such that the bitumen content and the bitumen penetration are similar to that of the fresh mortar. The designed LE2AP mortar contains 82.9% reclaimed material, new bitumen and rejuvenator. Their rate of application were controlled by the log-pen blending law of bitumen.

Table 4 presents the compositions of involved mixtures. Two types of LE2AP porous asphalt were produced at 110°C. One was produced by mixing hot LE2AP mortar at 170°C with PA-stone preheated to 120°C. The other was produced by mixing foamed LE2AP mortar with the reclaimed aggregates preheated to 110°C. In the mix design, the bitumen on the PA-stone is taken into account. It is assumed that 25% of the bitumen in or on the PA-stone is lost as active bitumen. This bitumen acts as black rock and cannot be reactivated. The other 75% of the bitumen on/in the PA-stone is active in the new mixture. This bitumen may either be reactivated or has penetrated the stone as pre-coating which binds the stone and the LE2AP mortar into the stone. In either case this bitumen becomes of value in the new mix. Due to the influence of the bitumen on the PA stone, the total bitumen penetration of the mixture decreases from 89 to 71 pen.

Figure 4. Materials obtained after decomposition: reclaimed mortar sand and PA-stone

Table 2. Descriptions of materials obtained after decompositions of reclaimed porous asphalt

Gradations passing sieves	*16 mm*	*8 mm*	*5.6 mm*	*2 mm*	*0.063 mm*	*Bitumen percentage*
Reclaimed mortar sand [%]	100	100	100	97.4	24.0	10.5
PA-stone 5/8 [%]	100	81.5	9.4	4.2	2.6	1.1
PA-stone 8/16 [%]	99.5	10.2	3.0	2.6	1.2	1.0

Table 3. Descriptions of LE2AP mortar compositions

	LE2AP mortar	*PA 0/16 fresh mortar*
0/2 mm reclaimed mortar sand [%]	82.9	-
Rejuvenator [%]	0.9	-
Crushed sand 0/2 mm [%]	-	52.4
Factory produced filler [%]	-	21.9
70/100 bitumen [%]	16.2	25.7
Total bitumen content [%]	25.8	25.7
Percentage reclaimed materials [%]	82.9	0
Expected penetration [0.1 mm]	89	89

Table 4. Descriptions of mixture compositions

	LE2AP PA with hot mortar	*LE2AP PA with foamed mortar*	*Fresh PA 0/16*
PA-stone 8/16 [%]	57.3	57.3	-
PA-stone 5/8 [%]	23.1	23.1	-
LE2AP mortar [%]	14.8	14.8	-
Bestone 11/16 [%]	-	-	21.1
Bestone 8/11 [%]	-	-	36.4
Bestone 4/8 [%]	4.3	4.3	24.9
Crushsand 0/2 [%]	-	-	9.1
Factory produced filler [%]	0.50	0.50	3.1
Baghouse dust [%]	-	-	1.0
70/100 bitumen [%]	-	-	4.4
Bitumen content in [%]	4.4	4.4	4.4
Percentage recycling[%]	93	93	0
Penetration of mixture [0.1 mm]	71	71	89
Production temperature [°C]	110	110	165
Mortar production method	Hot	Foam	-

3.3 *Mortar design*

In order to verify the properties of the LE2AP mortar, complex modulus and phase angle master curves were determined by using the Dynamic Shear Rheometer (DSR). In the DSR, a special mortar column setup with a height of 20 mm and a diameter of 6 mm is hereto used (Huurman et al 2010). During the measurement, the specimens were subjected to a sinusoidal loading signal at a range of frequencies and temperatures. DSR response tests were executed on both fresh and aged LE2AP mortars. Aging was achieved by placing 2 mm thick mortar slabs in a stove at 135°C for 44 hours. It is expected that the aging hardening that is obtained in this manner is equivalent to 10 years of aging of porous asphalt in the Netherlands (Jemere 2010). Figure 5 presents the complex modulus and phase angle master curves of the mortars before and after aging. The presented master curves are made at a reference temperature of 20°C. Figure 5 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. The results clearly indicate that LE2AP mortar produced based on reclaimed mortar has aging properties that are similar to the aging behavior of a freshly produced mortar. Since the behaviour at low frequencies is important with respect to raveling (Huurman et al 2010), the result indicates that the LE2AP porous asphalt will have the same field performance as a freshly produced PA.

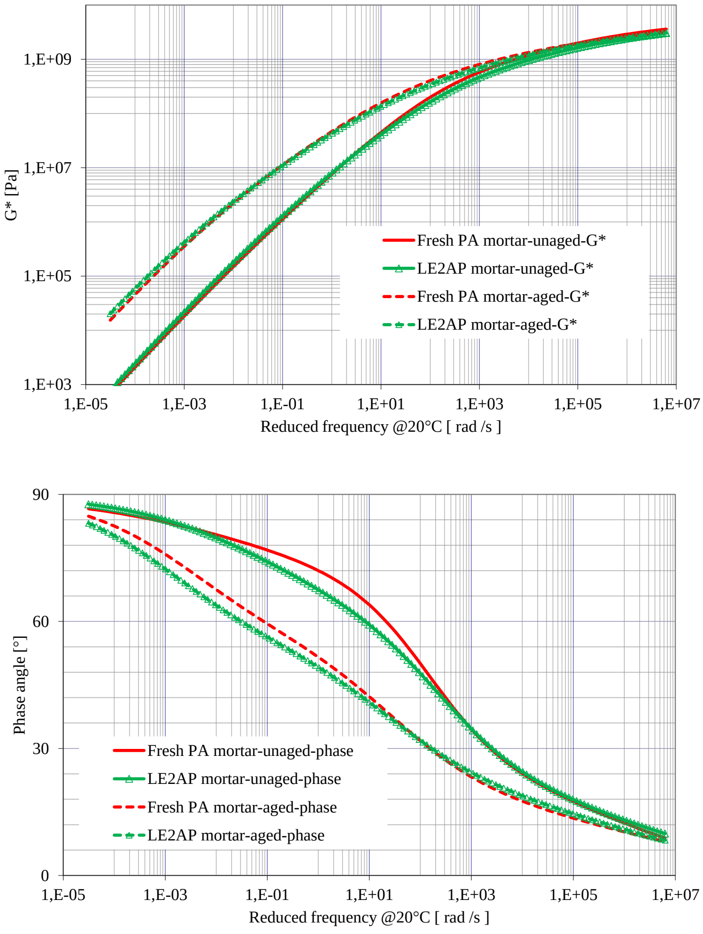

Figure 5. Response test on mortar columns

3.4 *Mortar foaming*

In order to produce porous asphalt mixtures at a lower temperature, the LE2AP mortar is foamed. However, due to the presence of the sand and filler in the mortar the existing bitumen foaming system cannot be used. This implies that a totally new foaming system is necessary for foaming of LE2AP mortar. Figure 6 gives the illustration of the laboratory scale mortar foaming unit. This unit contains a heated mortar mixer to ensure the homogeneity of the produced LE2AP mortar at a temperature of about 170°C. From the mixer the mortar may be pumped to a foaming nozzle with water injection. In order to improve the quality of the obtained mortar foam, 0.4% foaming additive was used.

Figure 7 gives the results of some mortar foaming tests. The expansion factor of the obtained foam may reach a value of 10 and the half-life is above 200s. The half-time of mortar foam thus is even longer than the half-life of the bitumen foam. During the foaming experiment, it is also noticed that the temperature of the foam remained at about 110°C, which is slightly higher than the temperature of bitumen foam due to the presence of the hot sand and filler fraction. In particular, no segregation of the sand and filler was observed during foaming. As a result, it is expected that with this mortar foaming technology, a good quality warm porous asphalt containing a high percentage of recycled materials can be produced.

Figure 6. Illustration of mortar foaming device

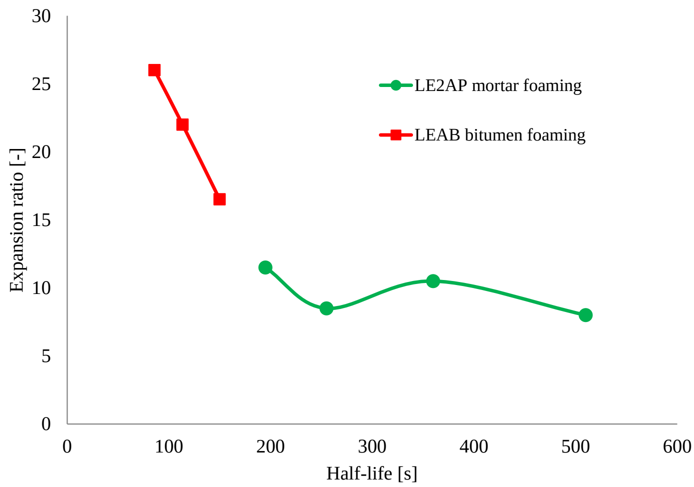

Figure 7. Results of the mortar foaming tests

3.5 *Mixture performance*

Three types of asphalt mixtures were produced in the laboratory and used to make slabs of 50cm x 50cm x 6cm. The production process closely resembles production and compaction procedures in practice. First, the mortar was produced with the mortar production unit. Then the mortar with or without foaming was mixed with the pre-heated reclaimed PA-stone. Afterwards the obtained mixtures were compacted using a small, but full scale steel roller. After production, the produced slabs were subjected to oven ageing at 135°C for 44 hours to simulate the effects of field aging. It has to be noted that there are continuous discussions in the field of asphalt ageing research that no laboratory accelerated ageing can simulate 100% of the field ageing. However, the ageing method used in this research is both practical and of ample quality to be used for ranking purposes.

In order to evaluate the ravelling resistance of the produced porous asphalt slabs the Aachener Rafelings Tester, ARTe, was used according to Annex A of prCEN-TS 12697-50:2014. The ARTe is specifically designed to determine the raveling resistance of surface layers, and more specific of porous asphalt. The ARTe itself is an accelerated loading test. One of the important indications from the ARTe is the stone loss after loading, which is an indicator for ravelling susceptibility and thus the durability of the surfacing system.

As shown in Figure 8, the slab is fixed in a slab fixation box and is moving forwards and backwards. During this movement, a set of two wheels rotates about a vertical axis while applying a vertical load of 2500N to the test slab. The combined movements of the wheels and the fixation box result in the application of large shear stresses to the slab surface acting to eat away individual surface stones, i.e. raveling. The speed of the loading table is 0.3±0.03 m/s during the time that the wheels travelling over the slab. The tyre pressure of the rotating wheels is about 200±10 kPa during the test and the rotation speed is about 47±1 rpm. The test is conducted at a controlled temperature of 20°C. According to the test norm each slab is subjected to a total of 600 cycles. After 300 cycles the slabs are rotated over 180° for another 300 cycles. During the period, the stone loss in mass is recorded as ravelling susceptibility.

Figure 8 gives the results of the ARTe tests for the two porous asphalt slabs. Unfortunately, the results of the porous asphalt mixtures produced by mortar foaming were not fully available at the moment of the paper was written. As a result, only the results from the other two types of mixtures are shown in the mixture performance section. Slight stone loss over time can be observed. Considering the variation of the ARTe experiment, the two plates are considered to be identical with respect to raveling susceptibility. It can be concluded that the new recycling technology enables the production of mixtures with 93% reclaimed material that s behave similar to freshly produced porous asphalt mixtures. Although results for the foamed variant are not available, it is believed that warm porous asphalt produced by foaming reclaimed mortar will have raveling properties that equal those of a freshly produced hot mixture. This is because it was observed that wetting of the reclaimed stone and the workability of the obtained mixture are both better than that of the warm mixture involved in these tests.

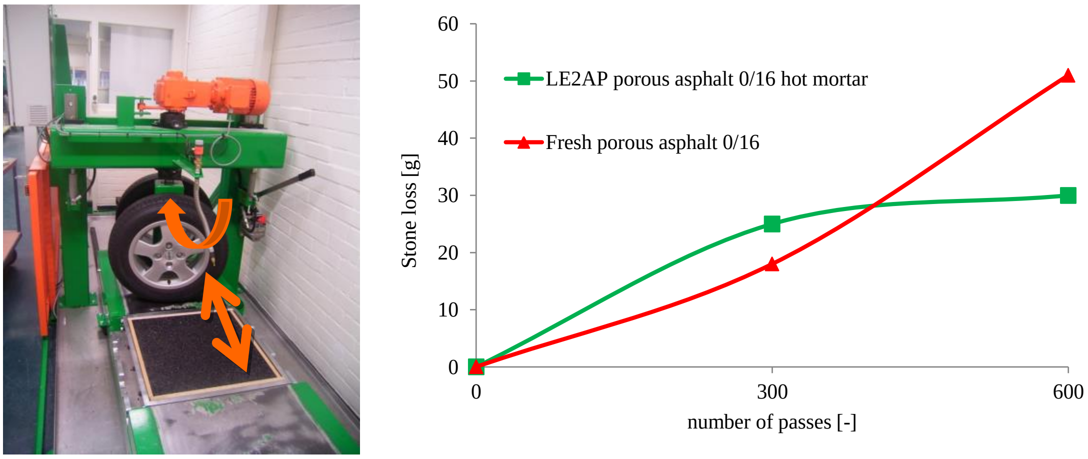

Figure 8. Illustration of the ARTe and results of the ARTe tests

4 CONCLUSIONS AND RECOMMENDATIONS

Based on this study, the following conclusions can be drawn:

1. Horizontal recycling of asphalt mixtures with warm technology is possible with no compromise in mixture quality;

2. By using the foaming technology, warm bin/base asphalt mixture can be produced with the same performance based specifications as a hot mix. This mixture can contain up to 60% reclaimed asphalt and may be produced at temperatures as low as 110°C;
3. By using the effective separation and mortar upgrading technology, a warm porous asphalt mixture can also be produced with the same performance as a hot mix. This mixture may contain more than 90% reclaimed material and may be produced at temperature around 110°C;
4. Although it was not discussed in-depth in this paper, with the use of the warm horizontal recycling technology, the production of the mix requires less energy as hot mixes and the CO_2-emission is reduced substantially. For a mixture produced at a temperature around 110°C, 25% to 40% energy can be saved and at least 25% reduction of CO_2-emissions can be accomplished (van de Ven 2007). This implies that the warm horizontal recycling technology is much more sustainable than the hot mix with the same mix composition.

The following points are for the future work:

1. In collaboration with the Dutch Ministry of Transportation, Rijkswaterstaat, extensive field performance tests are being executed to evaluate the field performance of porous asphalt produced with the LEAB technology. At this moment, several test sections on the Dutch primary road network have been constructed. A monitoring program, designed to obtain field performance date is in place and the oldest test section performed well for 5 years now. Indications are that warm production reduces short term ageing and this reflects in a extend service life against ravelling.
2. Research is into the application of the LE2AP new recycling technology of porous asphalt is on going. At this moment, a semi-full scale test section about 600m^2 (about 60 ton asphalt) has been successfully realised with the designed porous asphalt. The porous asphalt was produced at a temperature 100-110°C and with a total recycling percentage of 93%. It is planned to upscale this technology in 2016 and to realise a 1 km porous asphalt wearing course with at least 7dB noise reduction, percentage reuse above 80% and mixture production temperature even lower than 80°C.

5 ACKNOWLEDGEMENTS

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6 REFERENCES

Csanyi, L.H. 1957. Foamed asphalt in bituminous paving mixes. *Highway Research Board Bulletin* 10(160): 108-122.

D'Angelo J., Harm E., Bartoszek J., Baumgardner G., Corrigan M., Cowsert J., Harman T., Jamshidi M., Jones W., Newcomb Dave, Prowell B., Sines R. & Yeaton B. 2008. *Warm- Mix Asphalt: European Practice*, Report FHWA-PL-08-007.

EAPA, 2013. *EAPA Asphalt in Figures 2013*.

Jacobs M.M.J., van den Beemt C.M.A., Sluer B.W. 2010. Successful Dutch experiences with low energy asphalt concrete. *11th International Conference on Asphalt Pavements: ISAP Nagoya, Japan*.

Jemere Y. 2010. *Development of a laboratory ageing method for bitumen in porous asphalt.* MSc thesis, Delft University of Technology, The Netherlands.

Jenkins K.J. 2000. *Mix design considerations for cold and half-warm bituminous mixes with emphasis on foamed bitumen*. PhD Dissertation, University of Stellenbosch, South Africa.

Huurman M., Mo L.T. & Woldekidan M.F. 2010. Unravelling porous asphalt concrete, towards a mechanistic material design tool. *Road Materials and Pavement Design* 11 (3):583-612.

Huurman M. 2015. Low Emission2 Asphalt Pavement, LE2AP. *6th Eurasphalt & Eurobitume Congress 2016: Prague, Czec.* In press.

Van de Ven M.F.C., Jenkins K.J., Voskuilen J.L.M. & van den Beemt R. 2007. Development of (half-) warm foamed bitumen mixes: state of the art. *Special Issue: foamed asphalt for Pavements, International Journal of Pavement Engineering,* ISSN 1029-8436, 2007.