Sustainability & Environment

LE2AP, towards sustainable 100% surface-to-surface warm in-plant asphalt recycling

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Abstract

The historic Paris Agreement on Climate Change aims to keep the global temperature rise limited to preferably 1.5°C but no more than 2.0°C in this century. The Dutch government and Rijkswaterstaat also stated their ambition of having a 50% circular and 100% climate neutral asphalt industry in 2030. As such, sustainable technologies enabling low temperature production and high percentage recycling are increasingly important. With the support of the European LIFE+ program, a technology is developed allowing the production of high quality surfacing layers (SMA and PA) comprising up to 95% reclaimed asphalt surfacing layer at 105-115°C. The reclaimed asphalt is first decomposed into reclaimed stone with 1% bitumen and the reclaimed mortar with 10-12% bitumen. The reclaimed mortar is heated, rejuvenated, enriched and homogenised to obtain a high-quality mortar, which is then foamed and mixed with pre-heated reclaimed stones of around 100°C, to produce new surface layers with high quality. This paper aims to discuss the production technics which enable the full-scale demonstration of this technology, especially the main challenge: realization of the mortar production line. The paper discusses three development phases. Phase I, proof-of-concept: a mortar line was developed for the production and installation of porous asphalt test sections in 2016 using makeshift equipment with a production speed of 20 ton/hour. Phase II, optimization: the mortar line is further optimized during the demonstration of SMA sections in 2018, using the makeshift equipment and with a production speed of 80 ton/hour but still limited capacity. Phase III, industrialisation: in this phase the aim is to develop a mortar line which is to be incorporated in an asphalt plant allowing full capacity production of high-quality surface layers comprising up to 95% reclaimed asphalt produced at 105-115°C with limited energy use and CO2-emissions and even larger reduction of CxHy and other pollutants.

This paper was first published in 2020 in version 1.0 of the proceedings of the 7th E&E Congress. This second edition (version 1.1.) of the proceedings is published in June 2021. The content of this paper has not changed, but the author(s) may have provided additional information in the form of an annex.

1. INTRODUCTION

The historic Paris Agreement on Climate Change aims to keep the global temperature rise limited to preferably 1.5°C but no more than 2.0°C in this century. The Dutch government and Rijkswaterstaat (Dutch National Road Authority) also stated their ambition of having a 50% circular and 100% climate neutral asphalt industry in 2030. Asphalt surfacings, especially porous asphalt and SMA, are mostly constructed with costly high-quality bitumen and high-quality aggregates (e.g. high Polish Stone Value). In current practice, circular surface-to-surface recycling are less developed (limited to 30% for PA, 0% for SMA) and such surface layers are mostly downcycled to binder or base layers which is a waste of valuable resources.

It is known from the literature that there are at least two main challenges/concerns by surface-to-surface recycling, especially for porous asphalt and SMA if the traditional recycling method is followed.

- **Black Rock and Partial Blending**: The highly aged bitumen (penetration of 10) in the reclaimed asphalt are difficult to active again and to participate in the new mixture during recycling, especially for a recycling percentage up to 100%, which creates the so-called "Black Rock" problem. The use of rejuvenators or soft bitumen can cause a phenomenon called "partial blending" due to the limited blending and diffusion action during the recycling process [1].

- **Inhomogeneity**: Inhomogeneity is one of the main reasons that favours in-plant technologies over that of the in-situ recycling technologies (e.g. recycling trains) with very limited temperature variation and limited variations in material compositions (bitumen content and gradations) [2]. However, due to the high variability of the RA itself, especially the fine fractions and the bitumen content, plant produced mixtures can also not contain more than, e.g. 30% of the RA of mixtures, for surfacings such as PA [3].

All these concerns ask for an alternative way of surface-to-surface recycling of asphalt, which must guarantee both mixture quality and production quality as well as environmentally friendly. With the support of the European LIFE+ program (2013-2016), under a project LE2AP (Low Emission2 Asphalt Pavement), such a technology has been developed allowing the surface-to-surface recycling up to 95% at a production temperature of 100-110°C. The key advantages of this technology are as following [4,5].

- This LE2AP technology first decomposes the RA into its basic components then reuses them: the reclaimed stone (>2 mm) with 1% bitumen and the reclaimed mortar (bitumen-sand-filler system, <2 mm) with 10-12% bitumen. This decomposition process resolves the inhomogeneity problem mentioned above.

- The reclaimed mortar, which contains most of the bitumen, is treated separately involving indirect heating, rejuvenating, enriching and homogenizing. This process eliminates that issues of partial blending, inhomogeneity, oxidation or burning of bitumen in traditional asphalt production.

- To be able to produce this mixture in a sustainable way, the abovementioned mortar is foamed and mixed with pre-heated reclaimed stones of approximately 100°C, producing a mixture with up to 95% recycling at a temperature of 100-110°C.

This paper aims to discuss the developed technics involved in the LE2AP process in both laboratory and plant scales.

2. LE2AP: INNOVATIVE TECHNOLOGY FOR 100% SURFACE-TO-SURFACE RECYCLING

2.1. LE2AP Philosophy

As shown in Figure 1, a meso-mechanical model Lifetime optimization tool (LOT) developed in 2006 gave interesting insights by defining porous asphalt with two basic components, aggregates and mortar. The mortar (bitumen, filler and sand system) was defined as the binding medium for the aggregates [6]. With this insight, the LE2AP project was granted by European Life+ program in 2013, aiming at high quality of component level re-use of porous asphalt as aggregates and mortar [5].

Figure 1 gives an overview of the LE2AP recycling process. The reclaimed PA is first decomposed into its components; reclaimed mortar (< 2mm, with bitumen content 10-12%) and reclaimed aggregates (namely PA-stone, with bitumen content less than 1%). The reclaimed aggregates, PA-stone, can be directly reused replacing virgin aggregates. The mortar is then enriched, rejuvenated and homogenized to obtain LE2AP mortar with the same performance as its fresh equivalent. Finally, the LE2AP mortar is foamed and mixed with PA-stone to produce a mixture at a temperature of 100-110°C.

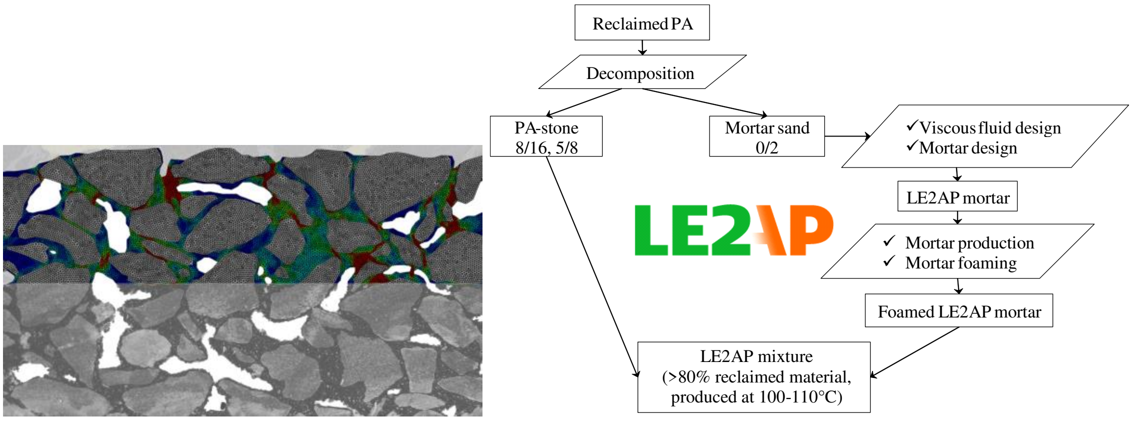

Figure 1: Images of 2D LOT meso-mechanical model (left) and the LE2AP recycling process (right)

2.2. Decomposition RA into stone and mortar

The decomposition process of the RA was carried out using a vertical impact shaft equipment (Figure 2a). The RA was fed into the middle of the equipment and thrown against a steel wall by centrifugal forces at very high frequencies, resulting in a brittle behaviour of the aged bitumen in the RA materials and therefore a pilling-off of the mortar from the aggregates.

Table 1 gives an example of the porous asphalt RA through the decomposition process. After the decomposition process, the average bitumen content on the reclaimed aggregate, PA-stone, is around 1%. The average bitumen content on the reclaimed mortar is about 10-12%.

Table 1: Typical results of porous asphalt RA before and after decomposition

Fractions [-]	Before decomposition	After decomposition			
	0-16 mm	8-16 mm	5.6-8 mm	2-5.6 mm	0-2 mm
Percentage [%]	100	30	20	20	30
Bitumen content [%]	3.5	1.0	1.1	1.4	10.5

Figure 2: a. the LE2AP decomposition process; b. reclaimed aggregates, PA-stone; c. reclaimed mortar sand

2.3. Reclaimed aggregates, PA-stone

As shown in Table 2, the PA-stone is similar to that of the virgin aggregates, and can be seen as a reclaimed aggregate, containing very limited amount of sand and filler. This, compared with the large sand/filler fraction and large amount of highly aged bitumen in the reclaimed PA, contributes to much better homogeneity and performance of the mixture, especially when recycling at higher percentage (>50%) [7].

Furthermore, attention has also been paid to identify the activity of the remaining 1% bitumen by investigating their contribution to the fracture energy of the mixtures. Mixtures with and without PA-stone were investigated with the same stone skeleton and mortar compositions. The results indicate that 50% of the remaining bitumen on the PA-stone is actively contributing to the fracture energy of the total mixture throughout the mixtures with a bitumen content between 3.5% and 5% [8]. These reclaimed aggregates can thus be seen as impregnate stones. The PA-stone is furthermore certified as a stone fraction instead of RA and can be directly used in production of new asphalt mixtures.

Table 2: Compositions of sieved reclaimed PA, PA-stone and virgin aggregates

Sieves passing	**22.4 mm** [%]	**16 mm** [%]	**8 mm** [%]	**2 mm** [%]	**0.063 mm** [%]	**Bitumen Percentage** [%]
Sieved Reclaimed PA 8/20	100	97.6	32.9	15.2	6.1	3.3
Reclaimed PA-stone 8/16	100	97.8	9.2	3.6	1.9	1.0
Bestone 11/16	100	88.5	3.5	1.1	0.4	0

2.4. Reclaimed mortar, LE2AP mortar

Table 3 shows typical compositions of mortars of the PA and SMA mixtures. It can be observed that all these mortars have similar gradations and a bitumen content around 25-30%. The reclaimed mortar obtained after the decomposition process gives similar gradations but with a bitumen content of around 10.5% and penetration of 10. To upgrade the reclaimed mortar into a LE2AP mortar, which has the same quality of the conventional mortar, correction was performed by adjusting the bitumen content and the bitumen quality. The adjustment of gradation for such bitumen-rich mortar was not necessary for such types of bitumen-rich mortars [4]. Table 3 gives an example of bitumen correction for the make of the LE2AP PA 0/16 mortar. The total penetration of the bitumen in the mortar was calculated by the log-pen relation of its components.

Table 3: Compositions of mortar of PA and SMA mixtures

Sieves passing	**4 mm [%]**	**2 mm [%]**	**0.5 mm [%]**	**0.063 mm [%]**	**Bitumen content [%]**	**Penetration [0.1 mm]**	**Bitumen correction (100/150 pen+rejuvenator)**
PA 0/16 mortar	100	97.1	57.3	29.4	25.8	89	
2LPA 16 mortar	100	98.2	64.3	39.3	29.0	89	
SMA 8B mortar	100	95.7	67.2	34.5	25.9	89	
Reclaimed mortar	100	97.4	68.1	24.0	10.5	10	
LE2AP PA0/16 mortar	100	97.4	68.1	24.0	25.8	89	16.2+0.9

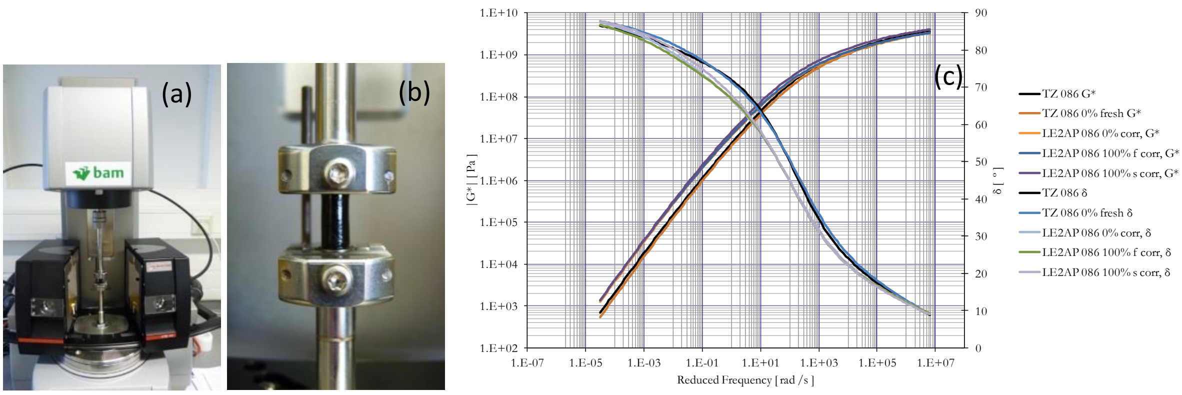

Figure 3: a. the DSR; b. the test setup; c. master curves of mortars at a reference temperature of 20°C

The DSR equipment and the mortar column setup with a height of 20 mm and diameter of 6 mm which was developed during the LOT project was used to investigate the performance of different mortars (Figure 3a, 3b). As a result, the LE2AP mortar in which the bitumen penetration and bitumen content were corrected, gave similar rheological performance than that of the standard mortar (Figure 3c). Further tests were also carried out for evaluating the performance after ageing (rheological, fatigue and so on) with the conclusions of equivalent performances [4].

2.5. Laboratory mortar production and foaming

Figure 4 shows a lab-scale mortar production/foaming unit developed during the LE2AP project. This unit can produce bituminous mortars with a maximum quantity up to 60kg (volume of 30L). During the experiments, the soft bitumen was first added to the mixer. Then the preheated reclaimed mortars sand 0/2 mm were added. At last the rejuvenator was added. The mixer blended continuously to ensure a good mixing of all the components. During the dosing process, pressurised water was injected in contact with the hot mortar to form a mortar foam.

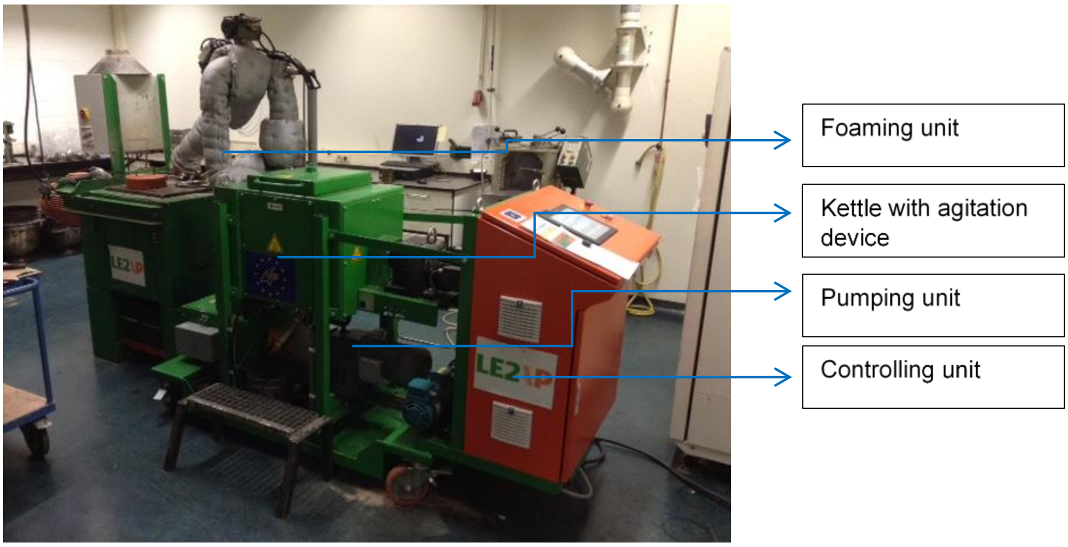

Figure 4: Mortar production/foaming unit

Figure 5a shows a photo of the foamed mortar obtained in this research. The foamed mortar has a higher temperature (around 110-120°C) than the normal foamed bitumen (around 100°C) [7]. No segregation of the sand and filler was observed during foaming process of the mortar. The average expansion factor of the bitumen foam is about 20 and the half-life is about 100s. The expansion factor of the obtained mortar 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.

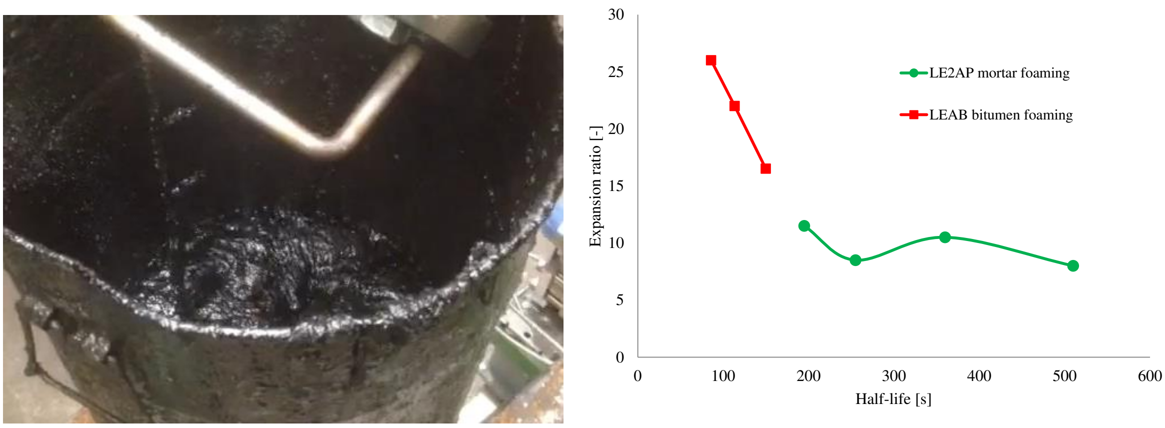

Figure 5: a. Illustration of the foamed mortar; b. Quality of mortar foaming

2.6. Mixture performance

Table 4 gives the mixture performances of different types of LE2AP mixtures and the standard mixtures (STD). The results indicate that the LE2AP mixture, when comparing with their hot variant, has a similar ITS strength and water sensitivity and slightly better compactbility. Furthermore, the ravelling resistance of the surface mixture of PA 0/16 was evaluated through Aachener Rafelings Tester, ARTe, according to Annex A of prCEN-TS 12697-50:2014. The results indicate that the LE2AP variant has similar ravelling resistance than that of the standard variant. It can thus be concluded that by using the LE2AP technology, it is possible to carry out surface-to-surface recycling at a reduced production temperature with no compromise in the mixture quality.

Table 4: Compositions and performances of standard and LE2AP mixtures

Mixture	PA 0/16		2LPA 16		SMA 8B	
	STD	LE2AP	STD	LE2AP	STD	LE2AP
Mixture code	TZ086	LE2AP086	TZ157	TB095	TS356	TS389
Total recycling	0%	93%	0%	96%	0%	78%
Production temperature	165°C	105°C	165°C	105°C	165°C	115°C
Reclaimed aggregates, PA-stone	-	80.0%	-	86.1%	-	60.0%
Reclaimed mortar	-	12.4%	-	10.1%	-	18.0%
New minerals	95.6%	5.0%	95.4%	0.8%	93.3%	14.7%
New bitumen/rejuvenator	4.4%	2.6%	4.6%	3.1%	6.7%	4.6%
Air voids	20.6%	20.6%	25.9%	25.2%	5.2%	4.7%
Nr of gyrations to reach target air voids [-]	73	55	30	21	265	46
ITS	0.81 MPa	1.06 MPa	0.70 MPa	0.65 MPa	1.32 MPa	1.40 MPa
ITSR	88%	85%	95%	86%	95%	97%

3. INDUSTRILAZATION OF THE LE2AP TECHNOLOGY

3.1. The decomposition process and the PA-stone line

With the successful laboratory results it is thus important to upscale the LE2AP technology and realize it in asphalt producing facilities. The use of the LE2AP technology involves three components, being

- The decomposition process,
- The PA-stone line,
- The mortar line.

The decomposition facility has been operational since 2015 at the location of the asphalt plant. The use of the decomposition facility for the reclaimed PA has been strictly regulated with quality controls specified for aggregate productions. Up until now, 200000 ton PA-stone has been produced and used in various mixtures and projects. Table 5 summaries the variation of the production of the PA-stone 8/16 in year 2016. It can be observed that the variation of gradings, especially for the sand and filler content is very limited, which makes producing a high-quality mix with high percentage recycling possible.

Table 5: PA-stone 8/16 production in 2016

Sieves passing	22.4 mm	16 mm	8 mm	2 mm	0.063 mm	Bitumen percentage
PA-stone 8/16 [%]	100	97.8	9.2	3.6	1.9	1.0
Standard deviation [%]	-	1.2	3.1	0.6	0.2	0.2

The PA-stone can be directly used in the asphalt plant using both the white drum and the black drum. Figure 6 and Table 6 give a comparison of production of porous asphalt mixture with 25% PA-stone through both the white drum and the black drum. The results indicate that both methods can result in a mixture with constant quality in terms of grading, bitumen content and compactability.

(a) (b)

Figure 6: Production of porous asphalt with 25% PA-stone through white drum (a) or black drum (b)

Table 6. Results of production of porous asphalt with 25% PA-stone through white drum or black drum

Sieves passing	**22.4 mm [%]**	**16 mm [%]**	**8 mm [%]**	**2 mm [%]**	**0.063 mm [%]**	**Bitumen Percentage [%]**	**Mixture temperature [°C]**	**Air voids Marshall specimens [%]**
Design Mixture	100.0	98.1	40.0	13.0	5.5	5.2	-	20.6
Mixture through white drum	100.0	97.2	40.4	12.8	6.2	5.1	150	18.3
Mixture through black drum	100.0	97.2	40.5	12.4	5.9	5.2	157	19.4

3.2. The mortar line: Phase I proof of concept (20ton/hour)

The industrialization of the mortar production line is one of the main challenges of the LE2AP process. There is no readily available technology for industrialising this mortar line. In the LE2AP project, a prototype mortar line was developed with the same principle of the laboratory unit through mastic asphalt technic in year 2015 and 2016 with makeshift equipments.

- First, the LE2AP mortar was produced using a small 2 ton heating kettle. The mortar sand and soft bitumen were heated and blended in the kettle at a temperature of 170°C (Figure 7a).
- Afterwards, these mortars were then transferred into a 15 ton heating buffer kettle and blended (Figure 7b).
- One hour before the production, rejuvenator was added in the 15 ton heating kettle per receipt. The reason for this later addition is to minimize the additional ageing throughout the mortar preparation process.
- During the production, the produced mortar batch was loaded to a heated dump cart and lifted using a crane a platform above the mixer (Figure 7b, 7c). The platform was designed with a heated dosing-pipe with 6 HD ultra-foam nozzles to the mixer. A special designed pressurised water injection system in the middle of the pipe was used to generate foaming action to the mortar.
- After the pre-heated PA-stone of 100-110°C discharged to the mixer, the mortar was discharged and foamed through the pipe to the mixer (Figure 7d).

This technology has been applied successfully in constructing a 600m^2 LE2AP PA 0/16 mixture section (2015). This leaded to the construction of 2.3 km LE2AP 2LPA test sections in 2016 on two Dutch provincial road N279 in Province Noord-Brabant and N338 in Province Gelderland, respectively [4]. Three PA mixtures were applied with 80-96% recycling and constructed at a temperature of approximately 110°C. Among these, two mixtures were designed with 80% PA-stone together with the LEAB bitumen foaming technology. The third mixture was designed with LE2AP 2LPA 16 (Table 4) with 95% recycling and produced with the LE2AP mortar foaming technology.

Figure 8 gives the temperature registration of the production of the LE2AP mixture during the section of N338. The average production temperature was intentionally increased from 110°C to an average of 130°C regarding the weather condition and the long transport distance to the jobsite, which resulted in the average temperature after the paver about 108°C (Figure 9).

Although it took more than 4 hours to produce about 80 ton of LE2AP asphalt in this phase, resulting a discontinuous production speed of about 20 ton/hour, this technology was proved to be workable at an industrial scale of producing surface layers containing up to 96% recycling materials and at a significantly decreased production temperature.

Figure 7. Production of LE2AP mortar with prototype mortar line

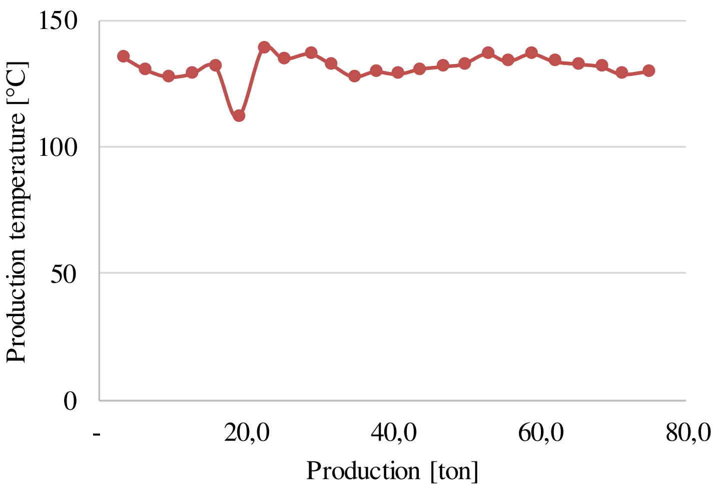

Figure 8. Temperature registration of LE2AP 2LPA 16 during mixture production of test trial N338

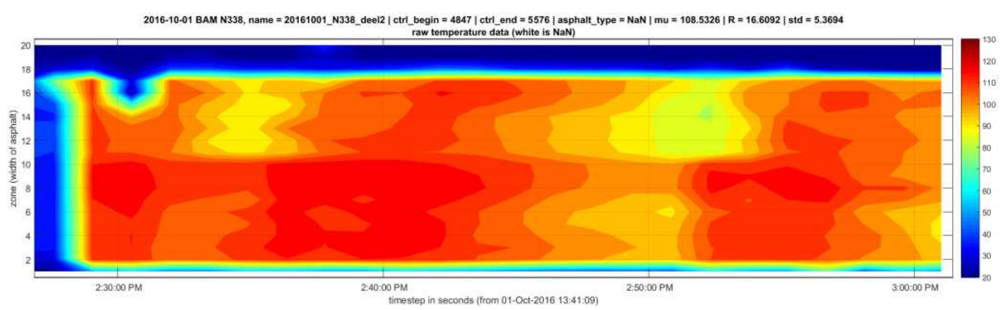

Figure 9. Temperature registration of LE2AP 2LPA 16 during laying of test trial N338

3.3. The mortar line: Phase II optimization (80ton/hour)

The LE2AP technology was further optimized in 2018 during the construction of the LE2AP SMA test sections by improving the production speed and the homogeneity of the produced mixture (Figure 10).

- A 50 ton steering kettle was used instead of 2 small kettles in the proof of concept phase (Figure 10a, 10b).
- An extra weighing unit is added between the steering kettle and the foaming nozzles to ensure the weighing precision of mortar (Figure 10c). During the production process, the LE2AP mortar was first dossed in the weighing unit. Afterwards the LE2AP mortar was discharged into the dosing pipe with foaming nozzles (Fig. 7d).

(a) (b) (c) (d)

Figure 10: Production of the LE2AP SMA mixtures with the optimized mortar line

This optimized mortar line has been applied within two SMA demonstration sections with a total length of 4 km in July 2018 on two Dutch provincial roads N317 of Province Gelderland and N625 of Province Noord-Brabant, respectively [8]. Within these sections, five mixture variants were applied evenly, being hot SMA mixtures with 0%, 20% and 60% PA-stones, mixture with 60% PA-stone and produced with bitumen foaming at 115°C, and the LE2AP SMA variant mentioned in Table 4. The total length of this LE2AP SMA variant was about 315 m. Table 13 and Figure 11-12 show the results of temperature registration by producing and laying the LE2AP mixtures and the STD variant. The production speed of the LE2AP SMA mixture was highly improved to 80 ton/hour with less variation than that of the STD variant.

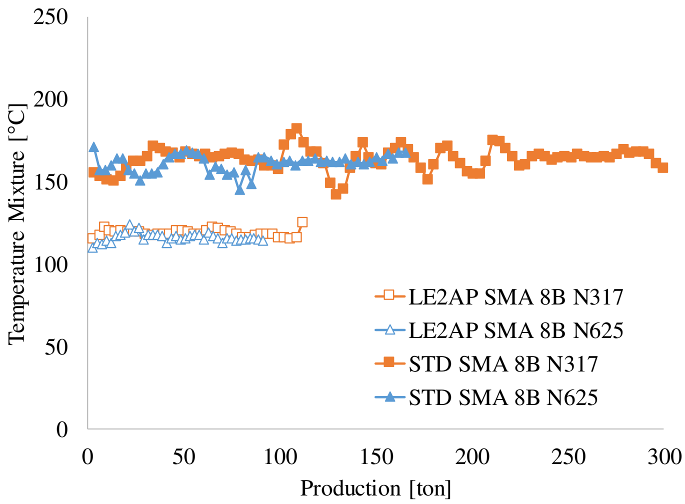

Figure 11: Production temperature registration of STD SMA and LE2AP SMA

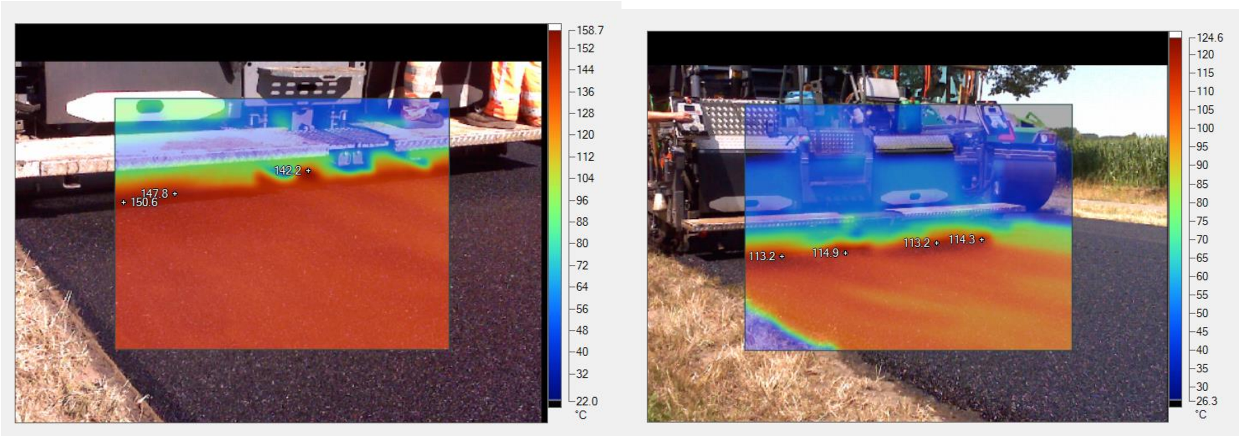

Figure 12: Laying temperature of STD SMA and LE2AP SMA

Table 13. Production temperature of LE2AP SMA and STD SMA mixtures

	N317			N625		
	Average production speed [ton/hour]	**Average temperature mixture [°C]**	**Standard deviation of temperature [°C]**	**Average production speed [ton/hour]**	**Average temperature mixture [°C]**	**Standard deviation of temperature [°C]**
LE2AP SMA 8B	74	118	2	75	116	3
STD SMA 8B	136	163	7	118	158	23

3.4. The mortar line: Phase III industrialisation

With the success of the optimization phase it is proven that the LE2AP technology has a great potential to be an 100% sustainable surface-to-surface recycling technology. It is thus important to industrialize and automate the mortar production line for asphalt plant for continuous production. BAM has received recently a grant from the Dutch government for developing such an automate mortar production line within 3 years. Figure 13 illustrates this system with an aim of continuous production speed of the LE2AP mortar at about 25 ton/hour, leads to a mixture production speed of 100-150 ton/hour. Research is in process, results will be soon published.

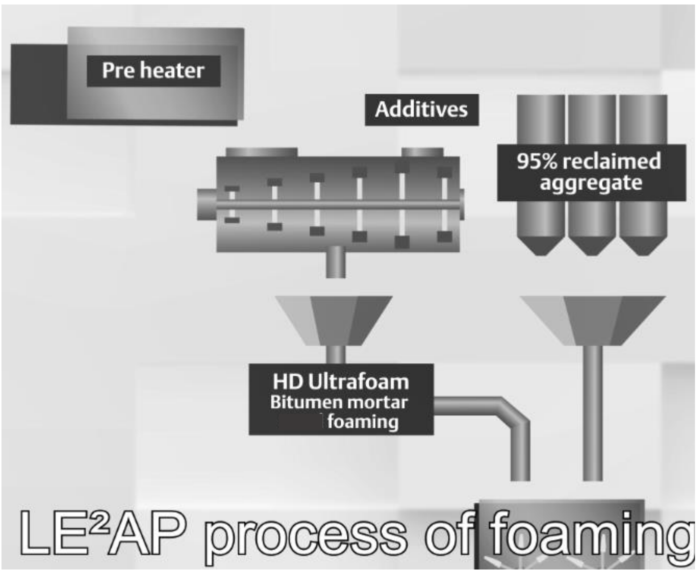

Figure 13: Industrialization of the LE2AP process in asphalt plant

4. ENVIROMENTAL BENEFITS OF LE2AP TECHNOLOGY

An LCA analysis was also carried out to access the environmental influences of LE2AP SMA mixtures by SimaPro v8.5.2 software. This LCA analysis was carried out using the cradle-to-gate principle by analyzing the A1 to A3 phases, from obtaining construction minerals (A1), to transport to the plant (A2) and to produce asphalt (A3) according to ISO 14040, ISO 14044, NEN-EN 15804 [9]. The reference databases for this analysis were,

- National Enviroment atabase version 2.2;
- EcoInvent database 3.4;
- SBK Bepalingsmethode, 25 mei 2018 (NMD 2.2) V3.04 / MKI-SBK single-score

The result of the LCA analysis was converted to an environment cost indicator (MKI), in which the environment cost by per ton asphalt production was expressed in Euros. Table 13 gives a comparison of such analysis between STD SMA and the LE2AP SMA. The results indicate that the use of the LE2AP technology will significantly reduce the environmental effect of asphalt production by a reduction up to 47% of the environment cost and a reduction of 45% for CO_2.

Table 13: Environment cost indicator of LE2AP SMA and STD SMA (1 ton asphalt)

	Production temperature [°C]	Recycling percentage [%]	Total MKI	MKI A1	MKI A2	MKI A3	Total CO_2-eq
STD SMA 8B	165	0	€ 7.37	€ 4.00	€ 1.47	€ 1.90	62.2
LE2AP SMA 8B	115	80	€ 3.92	€ 2.01	€ 0.38	€ 1.53	34.3
Difference	-50°C	80%	-47%	-50%	-74%	-19%	-45%

5. CONCLUSIONS AND RECOMMENDATIONS

This paper discusses the development of the LE2AP technology for a sustainable 100% surface-to-surface recycling. The following can be concluded from this paper,

- The LE2AP technology has been developed through decomposing the reclaimed asphalt into reclaimed aggregates and reclaimed mortar. The reclaimed aggregates can be directly reused as impregnated aggregates directly replacing virgin aggregates. The reclaimed mortar can be further rejuvenated, enriched and homogenized obtaining a mortar with the same performance as a fresh mortar. The use of this technology can overcome the challenges/concerns of current way of recycling, e.g. partial blending and inhomogeneity.

- Surface mixtures (PAs and SMAs) developed with the LE2AP technology, with a recycling percentage up to 96% and a lowered production temperature of 105-115°C, have similar mechanical performance than that of the standard equivalent.

- Using the mastic asphalt technology, a first mortar line has been developed for producing asphalt mixture at a lowered production temperature. This mortar line has been applied for various LE2AP field trials (PA, 2LPA and SMA) with success. The use of the mortar line allows more homogenies temperature distribution of the produced LE2AP asphalt than that of the standard hot variant. Next step is the industrialized development of this line with a continuous mortar production (continuous up to 150t/h asphalt production).

- The environment interventions and the associated CO_2 emission through the phase of A1 to A3 are reduced by 50% when compared with standard hot produced mixtures without recycling.

- All the constructed LE2AP test sections (PA, 2LPA and SMA) with the oldest trafficked section constructed at 2016 perform well by the time of the writing of the paper. Although not well described in this paper, other sections in which above 80% PA-stone was introduced in combination with the bitumen foaming technology resulting up to 80% recycling with a production temperature of 105°C perform also very well. All these sections are under continuous monitoring to provide useful information about the LE2AP technology. More than 200000 ton of the reclaimed aggregates, PA-stone, have been successfully produced and applied in various construction projects.

- Attention has also been paid to broader application of this technology for other material types (SMA, thin surfacings and dense asphalt) to be able to have a true circular recycling of asphalt surfacings.

The LE2AP technology has full potential as a 100% surface-to-surface warm in-plant recycling technology without jeopardising the mixture quality, which can greatly contribute to the goal of building a sustainable, circular and climate neutral of asphalt industry in 2030.

6. AKNOWLEGEMENT

The European Commission is acknowledged for their financial support through the EU LIFE+ grant. All the colleagues are thanked for making this development possible. Province Gelderland and Province Noord-Brabant are thankful for their financial support of the 2LPA and SMA demonstration sections.

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