RECYPMA

Final report
Management summary

Deliverable No 1.6

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Possibilities for high quality RECYling of Polymer Modified Asphalt

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Executive summary

Throughout Europe polymer modified asphalt (PMA) has been used extensively in the past decades for high trafficked roads and premium pavements; especially for surface layers. The addition of polymers contributes to the durability and functionality of these premium pavements. These pavements are now more and more reaching their end of life. Therefore the road sector is facing a rapidly increasing source of reclaimed asphalt (RA) that contains polymer modified bitumen (PMB) and high class aggregates, which might be used as high quality raw materials for new premium pavements. It is the challenge to the road sector to ensure that the "RA containing PMB" will be recycled at its highest practical potential. The goal in recycling is not to achieve the highest possible recycling percentage, but to **avoid downgrading of RA containing a potential valuable asset**.

The aim of the RECYPMA project is to investigate the possibilities for recycling polymer modified asphalt from surface layers into new high quality surface layers using hot mix recycling. The project should give answers to the following questions:

- What is the potential of using RPMA in new asphalt?
- What is the benefit?
- What (do we think, regarding the results of the project) should be done to get this implemented (technically) based on laboratory test results.

The result of the project has been described in 6 reports:

1. Report on state of the art
2. Report on the properties of aged polymer modified binders
3. Report on asphalt mixtures using RA containing polymer modified binder
4. Report on microscopy analyses of RA and asphalt mixes made in the laboratory
5. Report on the benefits of asphalt using polymer modified RA
6. Final report that summarises all the results and presents further research needs

Additionally a paper and a presentation to summarize the results of the project will be delivered.

This report concerns the final report of the project. It presents an overview of all project results for technical details readers are referred to the underlying reports. Besides this the report presents a vision of what knowledge is needed to create conditions for full scale application in Europe.

List of Tables

List of Figures

List of abbreviations

AC	Asphalt Concrete
DSR	Dynamic Shear Rheometer
GPC	Gel Permeation Chromatography – molecular size distribution analysis
FTIR	Fourier Transform Infrared spectroscopy
LCA	Life Cycle Analyses
LCC	Life Cycle Cost
PA	Porous Asphalt
PGB	Pen Grade Binder
PMB	Polymer Modified Binder
PMA	Polymer Modified Asphalt – asphalt produced by using a preblended polymer modified binder (like EN 14023) or by adding the polymer directly into the mixer of the asphalt plant which means no initial binder to test.
RA	Reclaimed Asphalt (US version: RAP - Reclaimed Asphalt Pavement)
RAD	Reclaimed Asphalt of SMA from Denmark
RAN	Reclaimed Asphalt of PA from the Netherlands
RAS	Reclaimed Asphalt of AC from Slovakia
RPMA	Reclaimed Polymer Modified Asphalt
SBS	Styrene – Butadiene – Styrene co-block polymer, elastic polymer
SMA	Stone Mastics Asphalt

Table of content

1 Introduction

Throughout Europe polymer modified asphalt (PMA) has been used extensively for several decades for high trafficked roads and premium pavements; especially for surface layers. The addition of polymers contributes to the durability and functionality of these premium pavements, such as noise reducing pavements (the Netherlands) or rutting resisting pavements (Denmark and Slovakia). These pavements are increasingly approaching their end of service life. Therefore the road sector is facing a rapidly increasing source of reclaimed asphalt (RA) that contains polymer modified bitumen (PMB), which offers a potential premium binder and aggregate contribution. Depending on the hardened state of the binder and the deterioration of the aggregate gradation during milling and further pre-processing, it is a challenge to the road sector to ensure – as far as possible – that the RA containing PMB is recycled at its highest practical potential. The goal in recycling is not to achieve the highest possible recycling percentage, but **to avoid downgrading of RA containing a potential valuable asset**.

The RECYPMA (RECYcling of Polymer Modified Asphalt) project is part of the program “ENR2 Design: Rapid and Durable Maintenance Methods and Techniques”. The "ERA-NET ROAD II - Coordination and Implementation of Road Research in Europe” (ENR2) program is a Coordination Action funded by the 7th Framework Programme of the EU.

1.1 Aim of RECYPMA project

The aim of the RECYPMA project is to investigate the possibilities for recycling polymer modified asphalt from surface layers into new high quality surface layers using hot mix recycling. The project should give answers to the following questions:

- What is the potential of using reclaimed polymer modified asphalt in new asphalt?
- What is the benefit?
- Which steps should be taken to technically implement this recycling process?

To ensure a diversity that is relevant for Europe, a broad departure is taken through the state-of-the-art review (report 1), followed by gradually focusing to three types of RA asphalt mixtures (one per participating country), one type of polymer modification and one type of pavement application (surface layer) for determining the binder properties (report 2). Based on the results three asphalt mixtures are designed with the reclaimed asphalt in order to determine the asphalt properties and quality (report 3). To assess the quality of the produced asphalt microscopy images are made of the mixes and the RA (report 4). At the end, based on the results of WP 2, 3 & 4, focus is made on a specific road case for estimating environmental and economic benefits (report 5). An overview of the results together with recommendations for further research are presented in a final report (report 6). Additionally a paper and a presentation to summarize the results of the project will be delivered. These six reports are all focussed on the overall aim of the project.

1.2 Objective and structure of the final report

The RECYPMA project has run over two years and has resulted in five reports that together fill over 200 pages.. This report aims to give a complete but condensed overview of the results and their implications for the recycling of premium surface layers into new surface layers.

The structure of the report is as follows. Chapter 2 summarizes the state of the art. Chapter 3 describes the materials that are used in this research. In chapter 4 the main conclusions of the binder study are presented. Chapter 5 shows the effects of RA on performance of mixtures. Chapter 6 presents an overview of the observations made with the help of microscopy. In chapter 7 the economic and environmental benefits are presented in short. The next and final chapter is dedicated to a condensed conclusion a discussion on what knowledge is needed for full scale application.

2 State of the Art on recycling of polymer modified asphalt

2.1 Focus and aim of literature review

As the project focuses on recycling of surface layers into high quality new surface layers the state-of-the-art portrays documentation that especially highlights the added value of polymers in RA. For basic information on conventional hot mix recycling technology readers are referred to literature, e.g. (Van den Bergh & van de Ven 2009). As a second objective the literature review has searched for laboratory extraction methods that allow characterisation of the bulk properties of an aged polymer modified bitumen. A third objective was to formulate a method for laboratory mixing for mixes containing polymer modified RA. It is not possible to disclose all details found in literature here, for this the reader is referred to the underlying report (Nielsen 2013a). The following statements highlight the most important findings.

2.2 Extraction and recovery

The SBS (Styrene-Butadiene-Styrene) type polymer modification studied in this research is by far most generally applied polymer-type in hot mix asphalt production. Through literature review and a dedicated questionnaire sent out to leading laboratories and research institutions in Europe the following two conclusions were drawn with respect to polymer modified binder extraction:

- for practical purposes the European standards EN 12697-1 and -3 can be used to recover a representative bituminous binder irrespectively of the solvent used;
- In this project dichloromethane (methylene chloride) is used as solvent for the extraction and recovery of SBS-polymer containing bituminous binder from the reclaimed asphalts.

2.3 Laboratory mixing

Based on the literature review a laboratory mixing procedure consisting of several steps is formulated. The procedure aims to produce a representative asphalt mix containing recycled polymer modified asphalt. It will not try to mimic full scale production, since there is a huge difference in mixing efficiency and conditions in the asphalt plant and in the laboratory mixer. The mixing procedure mentions the order of adding the components and the considerations for determining the mixing temperature (depending on the properties of both the reclaimed binder and the virgin bitumen). The mixture procedure is described in the state of the art report (Nielsen 2013a) and in the asphalt mixture report (Komačka, et al. 2013).

2.4 Experience with utilisation of RA containing PMB in full scale production

As the use of polymer modified bitumen in hot mix asphalt on a major scale has only started a few decades ago, only recently the amount of high quality RA is reached where selective recycling has become technically and economic feasible. As a result the amount of well documented experience found in the literature is very limited. Therefore this part of the literature study has only resulted in a listing of challenges that are recognized when aiming for recycling of polymer modified asphalt into surface layers. These challenges are described below.

To be able to consciously “harvest” high quality RA from the road, information about the material is needed before milling is performed. Often limited information is present on applied materials in existing road sections. Next to this the aging level of the binder can provide restrictions for application. Some countries started with low modification levels (2-4%), the benefits of these light modified binders in new road sections are expected to be limited. Therefore there is a need for a test method that can assess the quality and recycling potential of the binder in surface layers before it is harvested from a road section.

There are high requirements for the quality and size of aggregates for surface layers. Therefore Information is required on the type of aggregates in the RA. Next to this the grading curve of the new mix provides restrictions. The RA may contain an amount of fine grained material (sand and fillers) that limits the recycling percentage dramatically. The high amount of fines is caused by aggregate degradation during construction and milling and pollution during use (the last point especially for porous asphalt). Therefore there is also a need for information on aggregate type and grading before milling is commenced.

RA containing polymer modification has to be heated to high temperatures to ensure proper mixing with fresh materials. When levels of recycling above 15 % are aspired, cold mix addition of reclaimed asphalt is not feasible anymore and heating requirement results in specific demands for the asphalt plant, for instance the presence of a double drum mixer. RA containing polymer modified material is even more sticky compared to normal RA. This might provide problems with handling and processing of the material in the asphalt plant.

3 Materials

3.1 RA containing polymer modification

Three ‘‘old’’ SBS PMB-containing asphalt mixtures were reclaimed from typical surface layers of premium pavements in three different counties; stone mastic asphalt (SMA11) in Denmark, porous asphalt (PA4/8) in the Netherlands and dense asphalt (AC11) in Slovakia. The SMA mix was 22 years old, the binder used was Caribit Plus 85, a SBS polymer modified bituminous binder with a penetration range 70-100 dmm and a softening point above 75 ºC. The PA mix was 7 years old, the binder used was a Styrelf PMB 40/100-65 HD. The AC was 15 years old, the binder used was Apollobit MCA-S, a SBS polymer modified bituminous binder with a penetration ranging from 50 – 100 dmm and a softening point (SP) above 70 °C. All sections had an original SBS content of around 5%.

3.2 Binder extraction and virgin binders

Based on the results of the literature study extraction and recovery were performed according to European norms EN 12697-1 and EN 12697-3 on these three reclaimed mixtures to obtain three PMB-containing binders with abbreviations as RAD (SMA from Denmark), RAN (PA from the Netherlands) and RAS (AC from Slovakia).

In order to evaluate the benefits of the high quality RA for new asphalt mixes, two types of virgin binders were used, a normal paving grader binder (PGB) and a Polymer Modified Binder (PMB). The PGB is used to assess if the remainder of the polymer modification in the RA provides benefits for a new mix based on a normal binder. The polymer modified binder is used to assess the influence of the presence of an old polymer modified binder to the new mix. With help of the “LogPen rule” virgin binders were selected, which together with the old binders would result in the required binder penetration for the new asphalt mixes assuming a recycling percentage of 15 and 40 %.

For the Dutch and the Slovakian mix the following binders were used:

- **PGB1:** Q8, straight run bitumen, paving grade 70/100, provided by Kuwait Petroleum (Nederland) B.V.;
- **PMB1:** 70/100-83 (KR), modified bitumen by mixing 10% of D0243 SBS in B160/220 bitumen, produced by Kraton Polymers Nederland BV.

For the Danish mix, the following fresh binders are used:

- **PGB2:** 70/100, straight run bitumen produced by blending two different bitumen’s (40/60) and (330/430)) in the proportion 71.2 % and 28.8 % respectively.
- **PMB2:** 90/150-75, SBS polymer modified bitumen, provided by Colas Danmark A/S as a reference sample from their production of polymer modified bitumen’s.

3.3 Asphalt mixes

Three different types of asphalts for wearing courses (SMA, AC and PA) were designed and produced for laboratory testing. Five combinations of virgin material and RA were used for each type of asphalt, based on three RA contents (0 %, 15 % and 40 %). An overview of the mixtures is given in Table 1. The mixture with 0 % RA is used as a benchmark for the other mixtures. It was chosen not to test a mixture with PGB + 15 % RA, as irrespectively of the polymer content in the RA, a mixture containing 15 % RA would result in a total polymer level that is to low to expect any effect of the polymer as it won't be able to create a network.

Table 1: Matrix of tested asphalt mixtures

RA content of	SMA 11		PA 8		AC 11	
	PGB2	PMB2	PGB1	PMB1	PGB1	PMB1
0 %	x	x	x	x	x	x
15 %	–	x	–	x	–	x
40 %	x	x	x	x	x	x

Aggregate and fillers commonly used for the SMA11 production in Denmark, the PA8 production in Netherlands and the AC11 production in Slovakia were used in the scope of the project. More details on materials and mixture composition can be found in the specific project report on mixture performance (Komačka et al. 2013).

The binder content in reclaimed asphalts was determined by extraction procedure according to EN 12697-1. The obtained binder contents in RA are given below:

- RAN 5,42 %
- RAS 5,05 %
- RAD 4,60 %

The method of the production of mixtures is based on the literature review and is reported in detail in Komačka et al. (2013). The used mixing temperatures are based on viscosity measurements conducted on the binders reported in the binder part of this research (Liu et al. 2013).

4 Properties of extracted and blended binders

In order to asses the performance of the binder in new asphalt mixes containing virgin and reclaimed binder, the extracted binders from the RA are blend in the laboratory with virgin binder. High shear mixing is used to blend the binders, the aim of the blending procedure was to obtain an optimal blend. Due to practical limitation a lower level of blending is expected to be realized in practice. Optimal blending is chosen to provide an upper limit of properties that can be expected from the combined binder in asphalt mixtures. The level of blending is verified using microscopy. Table 2 gives an overview of the virgin, extracted and blended binders that were studied in the binder research. The original binder from the RAD material was still available from storage and was also characterized for comparison reasons. In order to determine the characteristics of the binders a variety of rheological and chemical tests were performed. The testing program for the recovered and blended binders included the following tests:

- Penetration, Softening Point
- DSR master curves
- Viscosity measurements
- FTIR
- GPC

It was decided to not perform laboratory tests on elastic recovery. This test is considered as relevant for the performance of PMB, however this test also requires a significant amount of binder. As the extraction effort that could be performed within this research was limited it was decided not to perform this test.

Liu et al. (2013a) provide detailed information on test methods and the complete test results. In this paper a short summary of the results is presented, in (Liu and al. 2013b) a more extensive summary of the results can be found.

Table 2: Overview of extracted, virgin and blended binders studied

Binder		RA content [%]	Fresh bitumen content [%]
Reclaimed	RAD	100	0
	RAN	100	0
	RAS	100	0
Virgin	PGB1	0	100
	PGB2	0	100
	PMB1	0	100
	PMB2	0	100
	Original binder RAD	0	100
Blended RAD	15%RAD+85%PGB2	13.5	86.5
	40%RAD+60%PGB2	36.5	63.5
	15%RAD+85%PMB2	13.7	86.3
	40%RAD+85%PMB2	36.9	63.1
Blended RAN	15%RAN+85%PGB1	15	85
	40%RAN+60%PGB1	40	60
	15%RAN+85%PMB1	15	85
	40%RAN+60%PMB1	40	60
Blended RAS	15%RAS+85%PGB1	15	85
	40%RAS+60%PGB1	40	60
	15%RAS+85%PMB1	15	85
	40%RAS+60%PMB1	40	60

Polymer in PMB is known to degrade to some extend during the service life of a pavement. This is also visible from GPC measurements on the extracted binder and the original polymer modified binder from Denmark. When the extracted binder is compared to the original binder, the size of the SBS molecules has reduced a little. However characterisation of all extracted binders demonstrates that a significant part of the characteristics of the polymer is still present. These characteristics can still be detected when the extracted binder is blended with virgin PGB bitumen or virgin PMB. Therefore it is concluded that it is possible to restore the rheological properties of the reclaimed PMB binder to its original state by mixing it with a soft virgin PMB binder. This is demonstrated in Figure 1 for RAD blends, it can be seen that the blended binder still shows phase angle characteristics that correspond to original polymer modified behaviour.

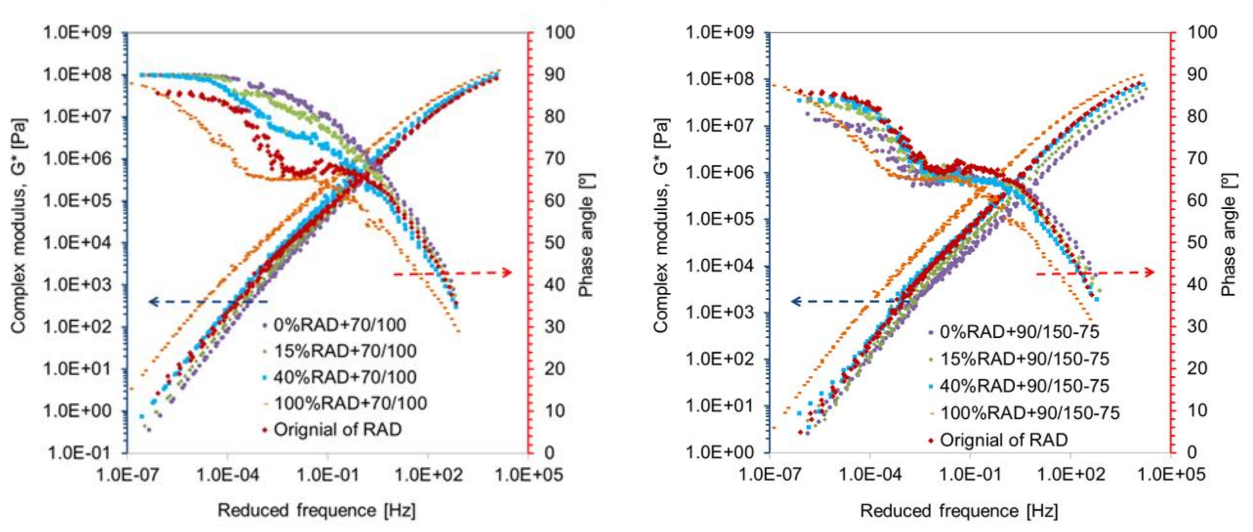

Figure 1: Mastercurves of virgin, extracted and blended bitumen from Denmark (RAD), left when blending with PGB, right when blending with polymer modified bitumen.

As the logPen. model and the softening point (SP) model both approximately predict the penetration value at 25 ºC and the SP of the blended binder for both with PGB and PMB blends, it is concluded that these models combined can be used for mixture design. For a more detailed mixture design a more elaborate prediction of the rheological properties, like viscosity at different temperatures and complex modulus at a wide frequency range, can be obtained through the Grunberg-Nissan model (Liu et al. 2013a).

Due to the polymer modification and aging of the binder, the required mixing temperatures for the blended binders are high, in some cases above 180 °C. As such high temperatures should be avoided to prevent degradation of the polymer, practical solutions to deal with this high temperature requirement needs attention in future research.

The SBS index from FTIR can be used to assess the relative SBS content of the reclaimed binder, this method however needs to be calibrated to the used type of SBS in order to be accurate. The GPC test can directly describe the degradation of the polymer when original binder is available as a reference.

5 Performance of asphalt mixtures with RA containing polymer modified binder

The aim of laboratory tests on asphalt mixtures was the investigation of the effect of the use of RA containing polymer modification on the properties of asphalt. The following tests were performed in order to assess the performance of the asphalt:

- **Water sensitivity test.** The ITSR values give information about durability with a respect to ingress of water.
- **Wheel tracking test.** The results provide an estimate of the resistance to rutting.
- **Stiffness and fatigue test.** The results can be used to estimate the structural life expectancy and will also give an impression of the integrity of the material.

All mentioned tests were carried out according to the relevant European standards.

In the project report Komačka et al. (2013) provide detailed information on test methods and the complete test results. In this paper a short summary of the results will be presented, in (Komačka et al. 2014) a more extensive summary can be found.

The ITSR values for all mixtures are high (the lowest value for SMA11 is 87.1 %, for AC11 88.2 % and for PA8 97.9 %). This means that the water sensitivity of the mixtures containing RA is expected to meet the requirements for surface layers. ITSR values for PA mixtures are very high (most of them are higher than 100 %). This might be caused by the basic nature of the filler, this behaviour is observed more often in the Netherlands (Giezen et al. 2012).

The ITS values also show a correlation between the tensile strength and the measured penetration of the blended binder as shown in Figure 2. Due to the extremely porous nature of this material of the PA8 mixture, this correlation is not present. The correlation indicates that the binder in the AC and SMA mixtures is blended to such an extent that it dominates the behaviour of the mixture.

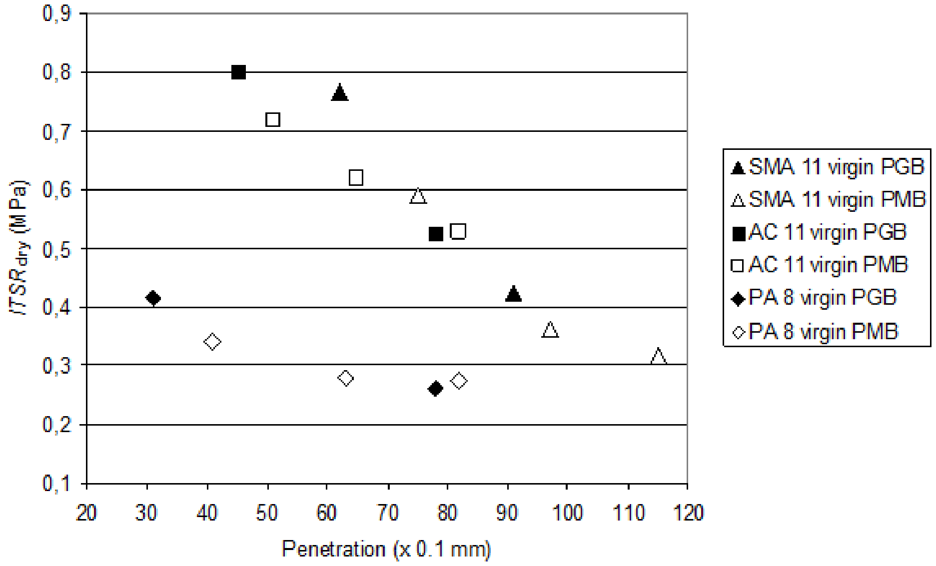

Figure 2: Relation between penetration and ITS value, AC11 and SMA 11 show a good correlation.

The wheel tracking test showed no rutting for all polymer modified binders. The mixtures with RA and PMB showed a similar performance compared to the benchmark PMB mixture. The mixture with PGB without RA showed a significant amount of rutting. The mixture with the PGB and 40 % RA showed a better performance with respect to rutting. This might indicate an advantage of the remaining SBS in the binder, however it should be noted that this could also be the effect of the aged binder which has a higher softening point.

The mixtures with RA containing PMB have a higher stiffness compared to the mixtures without RA. This could be an advantage because a larger stiffness leads to a higher bearing capacity. However if the stiffness is very high, this high stiffness could also result in brittleness at low temperatures. Therefore it is necessary to find a balance between needed stiffness and a risk of brittleness taking into account temperature conditions at a locality where a mixture is intended to be used. To further investigate this, low temperature cracking and properties test according to EN 12697-46 should be performed in future.

Fatigue tests are only required for the Slovakian AC mixtures, there are no fatigue requirements for the Dutch PA mixture and the Danish SMA mixes. As fatigue tests are very time consuming, it was decided that fatigue test were only performed on the AC 11 mixtures. The mixture with the PGB and 40 % RA showed better fatigue parameters compared to the mixture with PGB and no RA. On the contrary the mixture with virgin PMB was the most fatigue resistant and an addition of RA decreased fatigue performance and fatigue life. It is postulated that the SBS content in blended bitumen is an important parameter for fatigue performance. If this is the case, the remaining SBS in the RAS binder increased fatigue resistance of the mixture with PGB. As the SBS content in RAS binder is lower (± 5 %) compared to the SBS content of the virgin PMB1 (10 %) the RA mixtures have a lower SBS content compared to the reference mix and therefore show an inferior fatigue performance. Further research is needed to validate this hypothesis.

Based on the presented test results it is assumed that recycling of RA from surface layers into new surface layers will result in comparable asphalt performance for surface layers if recycling levels up to 40% are used. However this assumption still needs to be validated trough more extensive research as a limited number of asphalt mixes is tested with respect to a limited amount of performance characteristics.

6 Microscopy investigations of RA and asphalt mixes containing RA

Microscopy analysis of thin and plane sections has been performed as part of the research program to serve two goals, first to describe the three RA materials and secondly to provide a visual assessment of the new asphalt mixes (with and without RA, with PGB and PMB). All microscopy images and observations can be found in the relevant project report (Nielsen et al. 2013b). In this paper a short summary of the results will be presented.

The plane sections provide a notion on the build-up of the compacted asphalt mixture. The PA8 and the AC11 mixture look homogeneous, the SMA mixtures shows some inhomogeneity's. As Marshall compaction is used in this research, which is known to result in inhomogeneity's for SMA's, this is not further investigated.

The thin sections show qualitatively the presence and type of the dispersion of the SBS polymer trough typical yellow spots. As these spots can be observed in all RA materials it is concluded that polymer is still present in the binder, this coincides with the observed material behaviour of the extracted binder (Liu en al. 2013a).

Thin sections made of the asphalt mixes show some inhomogeneity's in the mixing. Parts of the mortar displays a homogenies mix, however at other locations a clear distinction between old and new mortar can be observed as displayed in the micrograph shown in Figure 3. These inhomogeneity's do not seem to affect the material behaviour, as tests on the asphalt mixtures showed a good correlation with the penetration of the optimal blended binders from the binder research as shown in Figure 2. As a better homogeneity is expected to result in a better performance, for future research it is recommended to investigate the level of mortar inhomogeneity with microscopy analysis of full scale plant produced mixes. In this case it is relevant if full scale production displays a similar level of homogeneity and whether or not prolonged mixing times influences the homogeneity modified bitumen.

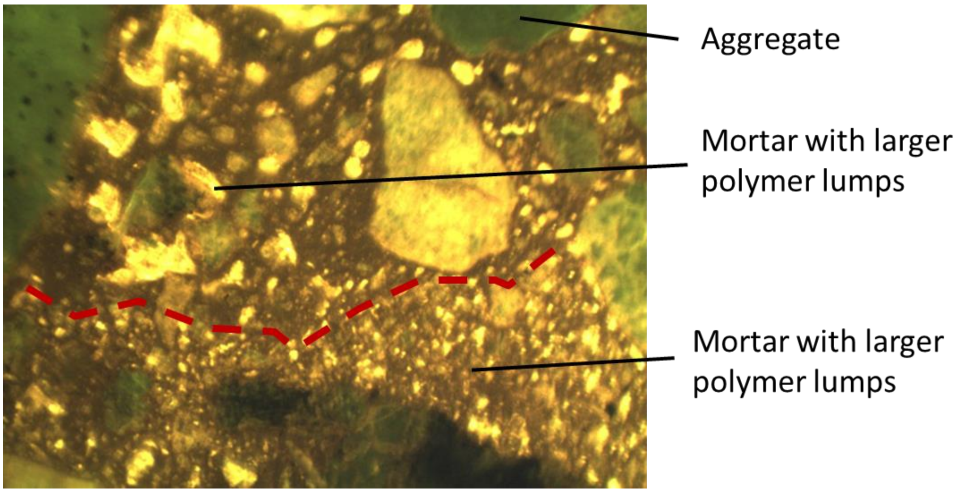

Figure 3: Details from micrograph of AC 11 with PMB and 40 % RA (Figure represents 0.80 x 1.06 mm)

7 Environmental and economic benefits

By replacing virgin material, recycling clearly reduces the amount of resources needed for new roads and the amount of waste that is produced both effects reduce the environmental impact of road maintenance. Recycling also provides a cost reduction as reclaimed asphalt (including the needed pre-processing required in the recycling process) is generally cheaper compared to virgin materials. PMB are especially expensive and if the originally present polymers could also be beneficial in the recycled product this would provide an interesting economical argument for recycling of asphalt containing PMB.

In order to quantify potential benefits of recycling of asphalt containing PMB an analysis of the environmental and economic impact of recycling of premium surface layers into new surface layers is performed. In this analysis a road surface layer made of asphalt containing PMB without any RA is taken as a reference and compared to a surface layer with recycled material containing polymer modification. Next to this a road with a PGB is taken as a reference and the effect of the addition of RA with polymer modification is assessed.

The basis for comparison is a pavement of 3.5 m wide, representing a driving lane of a main road, over a length of 1 km during 50 years. The materials and production processes are based on the binders and mixes that are used in the laboratory research described in the other project reports. Next to this questionnaires were sent out to contractors and material suppliers to obtain cost and hauling distances.

In order to obtain a complete image of the environmental benefits of recycling of polymer modified asphalt an LCA analyses has been performed. In this analyses the total recycling process, including all materials and processes is considered. Different methods available in Europe to assess the environmental impact are compared in the calculation to demonstrate the impact of a specific method on the calculated environmental benefits.

The analyses show that the effect of using recycled material on the environmental impact and life cycle cost is significant. The influence of the recycling percentage on the environmental loading is very clear: 15 % recycled material in the mix reduces the loading by around 10 %, 40 % recycled material in the mix reduces the loading by approximately 25-30 %.

The binder determines a significant part of the environmental impact: this is 40-55 %, dependent on the exact scenario, see Figure 4. The use of a PMB increases the environmental impact per kilogram binder. However, as it is assumed that PMB also has a positive influence on service life, this additional environmental loading of the material at construction is turned around into a net environmental benefit due to the longer service life that is realized with an equal amount of material.

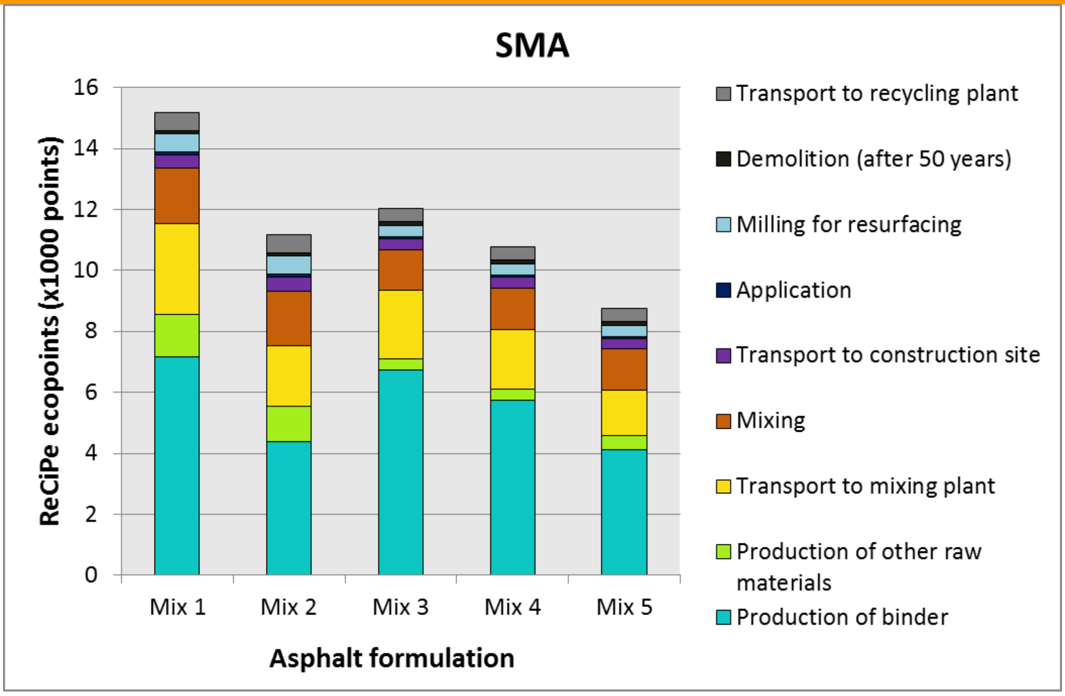

Figure 4: Environmental impact details of SMA top layer (single lane, 1 km, 50 years)

The used assessment method for environmental impact shows a modest influence on the calculated environmental impact. The assessment methods that were investigated (ReCiPe, EDIP and Ecological scarcity) produced the same trends. However as the principles of each method differ, e.g. in the Ecological scarcity method more weight is attributed to emissions to air and the depletions of materials compared to ReCiPe, the relative contribution of the binder to the environmental load varied significantly among the methods. As the binder was identified in the research as one of the main contributor, in some cases the different methods resulted in a different ranking for the five scenarios.

The assessed environmental impact is not very sensitive to variations in key starting points. However, service life assumptions have the large influence on calculated environmental impact. Therefore quantification of the influence of RA on the service life of surface layers is very important and should be studied further.

The cost analysis is focused on the effects of using RA containing polymers on the total costs of the mixture including the new polymer addition and the expected service life. The cost of PMB are based on country specific information obtained through interviews with contractors and manufacturers. The life expectancy of the road, which is also a part of the LCA, is based on the performance of asphalt as it is studied in this research (Komačka et al. 2013).

The recycling percentage has also distinct influence on the costs. 40 % recycled material in the mix reduces the Life Cycle Cost (LCC) of polymer modified asphalts by approximately 10-18 %. The relative costs of production and construction are also important factors in the LCC calculation. The cost of the binder is responsible for up to 70 % of the materials costs. The actual price level of binders can vary substantially over the years under the influence of the oil price, the exact cost level will determine the absolute cost reduction that can be achieved through recycling.

8 Conclusions and recommendations

Binder research indicates that the extracted binder from the RA with PMB still contains an active part of polymer that influences the material behaviour as can be expected from a polymer modification. Research on mixtures containing RA with PMB shows, that if proper mix design is used, a good performance in surface layers is realized with respect to water sensitivity, stiffness, rutting resistance and fatigue.

From an economic and ecological perspective, the benefits for National Road Authorities as well as the road sector are considerable because of the shorter hauling distances of aggregates and the reduction of primary resources mainly attributed to the binder. This is especially important for EU countries that are dependent on import of primary raw materials.

The results of the research indicate that there are technical possibilities for recycling of polymer modified surface layers into new premium surface layers and that the benefits of doing so are significant. However still many challenges lie ahead before large scale application is possible, first risks with respect to service life when using RA need to be quantified in more detail (e.g. the assumed relation between SBS content and fatigue performance, high stiffness of asphalt containing RA with PMB and the risk of low temperature cracking, etc.), issues related to full scale application (e.g. the risk of degradation of the polymer at high temperatures, mixing time influence on homogeneity and performance of asphalt) need to be explored and finally quality assessment and assurance of the RA has to be managed including the quality of the used aggregates. All three challenges can be met through research while realizing a series of pilot projects. These pilot projects are preferable realized in different European countries to incorporate different recycling techniques and different environmental conditions.

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