Asphalt mixture performance and testing

High-quality reuse of polymer modified Asphalt

Gerbert van Bochove[1], Koos Jol[1], Inge van Vilsteren[2], Dave van Vliet[3], Jan Voskuilen[4]
[1]Heijmans Infra B.V., [2]Dutch Ministry of Infrastructure and Water Management (Rijkswaterstaat), [3]TNO, the Netherlands Organisation for applied scientific research, [4] Groen Asfalt

Abstract

With the increase in the use of polymer modified bitumen (PmB) in new asphalt, the flow of old asphalt which PmB when replacing or renewing this asphalt, also increases. This stream of old asphalt with PmB is usually seen as a permissible "pollution" of the total flow of old asphalt, which is reused in new asphalt mixtures in the usual way. With the increasing amounts of old asphalt with PmB, there is also the possibility of collecting this asphalt granulate in a separate manner. This creates the possibility to reuse this material at the production of new asphalt with PmB. The old PmB then delivers added value in the new PmB modified asphalt, so that a higher-quality reuse is achieved. However, a number of technological challenges arise: Will it be possible to rejuvenated old PmB and bring it to the quality level of a new PmB? Will the mixing action cause a homogeneous blend of the old and the new binder? Does this affect the way of mixing and mixing time? Are outdated PmBs of a different origin and polymer family compatible with new PmBs? Questions that cause technologists all over the world to hesitate to enter this field. Heijmans Infra BV has taken up this challenge together with the Dutch Ministry of Infrastructure and Water Management (Rijkswaterstaat) and TNO, the Netherlands Organisation for applied scientific research. Earlier developed reuse and rejuvenating techniques for Porous Asphalt mixtures with normal bitumen are upgraded for the use of PmB Asphalt. The developed technique was applied at milling material from an old top layer of two-layer Porous Asphalt for use at 40% level in a new top layer. Relevant bitumen and asphalt properties have been intensively studied both fundamentally and functionally. The result gave reason to take serious steps on a practical scale.

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

Asphalt concrete is one of the large-scale applied building materials which is excellently suited for reuse. Because the end product (an asphalt road) is not created by a chemical process such as cementous concrete, but through the physical process of cooling down, this process is reversible. When warming up old asphalt, the bituminous binder will melt again, the constituent materials will be released and can be mixed with the newly added constituent materials.

In the challenge of making the economy fully circular, the task for the asphalt sector is: 100% reuse of asphalt. With 100% reuse it is therefore not meant that new asphalt mixtures should consist of 100% old material, but all old asphalt which is released in the maintenance and reconstruction of roads, is reused in the production of new asphalt. It is also important that all constituent materials applied in the asphalt mixture should be recyclable. In the current situation, the demand for new asphalt is still greater than the supply of reclaimed asphalt. This gives the possibility of adding new constituent materials in the various asphalt mixtures to achieve the desired target composition and properties in a manageable way. However, the reuse rate per mixture type may vary. As the requirements imposed on a particular asphalt mixture are higher, the applied reuse rates are often lower. Thus, according to most national standard provisions, the use of RA in surface mixtures like Stone Mastic Asphalt (SMA) and Porous Asphalt (PA) is limited or not allowed.

As the road network in most countries becomes more and more completed, the focus on maintenance increases, which leads to a gradually shift in balance between the quantity of desired new asphalt and reclaimed asphalt (RA). The reuse rates will therefore have to increase. The challenge for the industry is to take steps in asphalt mixtures where the existing rules don’t allow reuse. When additional research can demonstrate that even with the addition of old material the functional requirements of a new asphalt mixture can be fulfilled, space will be created to apply reuse also in these mixtures. In general the use of RA in this high quality asphalt mixtures is either linked to a specific process or to specific constituent materials. These “specials” allow for the application of RA in these surface mixtures in the distinction of standard recycling methods. This requires validation by an independent authority.

For PA mixtures in the Netherlands, the National Government is the most important user. Therefore, testing of PA mixtures with RA takes place at the Innovation Test Centre (ITC) of Rijkswaterstaat (a department of the Ministry of Infrastructure and Water Management. Several experts are available to test the finished product on functionality. They zoom in on risk factors and specific properties, which have a relationship with the applied process or the applied constituent materials. This contribution will examine an example of such an investigation.

1.1 Reuse of asphalt containing polymer modified bitumen

In general, surface layers contain high-quality constituent materials. Reuse of these materials in surface layers will lead to increasingly high-value reuse: the so-called horizontal recycling. For example, RA from old PA contains high quality stone with high resistance against polishing and crushing. Furthermore in some PA mixtures high quality bitumen is used, especially polymer modified bitumen (PmB). Reuse of this high-grade material in binder or base layers is in fact capital destruction. So application of this RA in new PA mixtures would be very desirable. This creates a whole new challenge: reuse of RA containing PmB in a new asphalt mixture with PmB. Will this product act at the same function level?

The first challenge is logistical: can this material be milled and stored separately? The increasing quantities of released PmB mixes creates the possibility to consider and handle this material as a separate material flow. But additional there are several technological challenges: Is it possible to rejuvenate an old PmB to the functional level of a new PmB? Does it mix well with the new binder in the recycling process? Does this still affect the way of mixing and mixing time? Are aged PmB 's of a different origin and polymer family compatible with the new PmB’s, or will this cause a 2-phase structure? Questions that concern not only technologists in the Netherlands, but also globally. However, not many steps have been taken yet. At most, these questions are used in a counterproductive sense: to inhibit and reject the use of PmB in new asphalt mixtures. However, this does not solve the problem and contradicts the circular objective of high-quality reuse.

1.2 Reuse of old PA 8 with PmB in new PA 8 with PmB

Heijmans has taken up this challenge together with Rijkswaterstaat and TNO. A project has been worked out on the reuse of material from an old PA 8 in a new PA 8 mixture. PA 8 is used in the Netherland as a top-layer for two-layer Porous Asphalt and contains a PmB as binder. A specific feature of PA is the fast and far-reaching ageing of the binder during its lifespan. This is due to the open structure of the mixture and thereby the intensive contact with oxygen and weather influences. This, as will appear later in this publication, also occurs with PmB. When the aged, hard PmB is simply mixed with a new PmB, available in the market, the ageing is not adequately compensated. In the vision of these researchers, a rejuvenator is needed to give the mixture of aged and new PmB the desired properties.

Besides this rejuvenation a specific recycling process is developed by Heijmans for its asphalt plants. The heated RA, the rejuvenator and the new constituent materials are not mixed at once in the end mixer of the asphalt plant, but in phases. The background for this is that the old PmB binder together with the rejuvenator requires time and temperature to make it suitable for homogeneous mixing with the new binder. Therefore, the rejuvenator is added to the RA in an earlier stage of the production process. In this process, after injecting the rejuvenator agent in the parallel drum containing the old asphalt, the coated RA is transported to an intermediate bunker, where it stays for approximately 10 minutes at approximately 120°C. At this temperature and during this "soaking time" the rejuvenator can do its work. In the final mixing process a homogenous new binder is formed consisting of the RA binder, the rejuvenator and the new PmB.

2. MIXTURE DESIGN

2.1 Composition of the RA

The RA of PA 8 has been mined by selective milling of the 25 mm thick top-layer of Two-Layer PA. Two sources of RA were investigated, coming from the Highways A50 and A2. By extraction, for each of the analyzed batches the grading, bitumen content and penetration grade of the RA have been determined. This is input for the design of the new PA 8 mixture. The target composition is based on the requirements for new PA 8 in accordance with the Dutch national regulations: Standaard RAW Bepalingen 2015 [1]. Design calculations have shown that the milled RA, as it comes from the road, is not suitable in the new mixture right away. The desired rate of 40% RA is feasible, provided that the fine fraction < 4 mm is removed by sieving. This sieving operation turned out to be well feasible with suitable equipment and the remaining RA fraction > 4 mm of the two batches of milling material (A2 and A50) was taken as the basis for further research.

2.2 Binder content and penetration

In addition to the consideration of the aggregate grading as described above, the binder content and the penetration is determined. As with most Porous Asphalt, the binder in the RA of the top-layer is heavily aged, see Table 2.1.

Table 2.1: Binder content and Penetration grade of the RA

RA material origin	Binder content [% (on aggregates)]	Penetration [0.1 mm]
Highway A50	3.7	15
Highway A2	3.4	8

The penetration of the RA (Reclaimed Asphalt) of the A2 is significantly lower than that of the A50. This, while in both mixtures the same bitumen has been applied: Styrelf 40/100-65HD (SBS base; see Table 2.2 for the properties). The difference in ageing therefore could be due to the higher production temperature or higher age and possibly also the longer storage time of the RA of A2. The binder in the A2 material will therefore have to be more worked up. Furthermore, it is clear (and also logical) that with the preprocessing (sieving) of the RA also a proportion of bitumen is lost: the original binder content in this top-layer mix of Two-Layer PA is higher.

2.3 Determination of the type and amount of rejuvenator

The procedure to select an appropriate rejuvenator falls outside the scope of this paper. In short, the most important selection characteristic is making a highly aged binder mobile, in a standardized amount of RA. This is tested by measuring the transfer of old, rejuvenated bitumen after the soaking process to new mixed-in stones. For this test a special soaking and mixing protocol is developed. By investigation both the quantity and the quality of the exchanged binder a conclusion can be drown about the real rejuvenation ability instead of a diluting effect.

The amount of the rejuvenator to be added is determined on the basis of a number of aspects. For the new binder to be added a regular PmB available on the market (Pen 55) is assumed; see Table 2.2 for the properties. Primarily the amount of rejuvenator is based on log-pen calculations with the penetration of the new PmB as a "target pen". This calculation rule is defined in Annex A.2 of NEN-EN 13108-1 and formulated below, where $x_1, x_2, \ldots, x_n$ are the portions by mass of the different binders in the mix with respect to the total binder content ($x_1 + x_2 + \cdots + x_n = 1$):

$$x_1 \times \log(Pen_1) + x_2 \times \log(Pen_2) + \cdots + x_n \times \log(Pen_n) = (x_1 + x_2 + \cdots + x_n) \times \log(Pen_{mix})$$

It is noted that the penetration, in particular for PmB bitumen, is only one of the quality parameters. Therefore, for various rejuvenator ratios, the preprocessing process which Heijmans applies in its asphalt plants (soaking with a rejuvenating agent in a certain combination of time and temperature (~10 minutes at 120°C)) is simulated in the laboratory. The semi-product resulting from this process (only RA + rejuvenator) is assessed for functional behavior (workability). This is a qualitative observation which is done in the laboratory, where a number of RA samples is mixed with varying ratios of rejuvenator at 120°C and stored for 10 minutes. Hereafter, the consistency of the mixture (i.c.: the viscosity of the mortar) is judged: binder drainage should be prevented, while the mixture also shouldn't be to dry.

The amount of rejuvenator, based on this method also gives a good indication that the semi-product, supplemented with the new constituent materials into a complete mixture, is well workable. This assessment has been the main factor to adjust the final amount of rejuvenation to be added. The behavior of the mixture in practice have shown that this method of determination is a right choice. Further studies have also shown that, after the soaking process with rejuvenator, the two PmBs (old and new) mix well and do not impair its functional characteristics (see later on). Table 2.3 gives an overview of the binder ratios for the two investigated mixtures with RA.

Table 2.2: Bitumen properties of the old (in the RA) and new binder

Property	Binder type	
	In RA (Styrelf 40/100-65HD)	In new mixture (new SBS)
Needle Penetration (Pen) [0.1 mm]	40-100	Needle Penetration (Pen) [0.1 mm]
Softening Point [°C]	≥ 65	Softening Point [°C]
Fraass breaking point [°C]	≤ -15	Fraass breaking point [°C]

Table 2.3: Various ratios binder for PA 8 top-layer mixture (both mixtures with 40% RA)

Source of RA		A50	A2
Amount rejuvenator related to RA		0.875	1.125
Part	Pen	Proportion binder in end product	
Total binder		5.40	5.40
New added PmB	55	3.57	3.59
Rejuvenator	56115	0.35	0.45
RA A50	15	1.48	
RA A2	8		1.36
Calculated Pen of the "rejuvenated" RA		72	72
Target penetration of the end binder in the mixture		60	60

2.4 Mixture calculations and type testing

On the basis of the Standard PA 8 mixture of Heijmans without RA, the grading of the RA and the binder ratios shown above, mixtures are calculated, on which the European Type Test procedure has been carried out. In addition, RSAT examination has been carried out to the most promising mixtures. RSAT (Rotating Surface Abrasion Test) is a ravelling test (prCEN/TS 12697-50) device developed by Heijmans by which the resistance against ravelling under traffic conditions can be determined. This test method had been validated in a comprehensive investigation by CEDR, see [2]. A brief overview of the Type Test and RSAT results of the reference mixture and the developed RA mixture is listed in Table 2.4. Even though the binder content in this mixture is rather high, binder drainage is not an issue, because of the relatively high viscosity of the PmB and the small aggregate size.

Table 2.4: Type Test and RSAT results

Mixture code	Description	ITSR	Air Voids	Stone loss RSAT [g.]	
				Average	Standard deviation
84307	Reference PA 8 (no RA)	83% ($ITSR_{80}$)	25.4 %	13.8	4.5
84347	PA 8 with 40% A2 RA	92% ($ITSR_{90}$)	20.9 %	5.6	0.4

From the RSAT results the mixture with RA seems to be even better than the reference mixture. This will also be related to the somewhat lower design air voids of the RA mixture, see above. The lower the air voids, the stronger the mixture. The other values in the table also meet the requirements of PA 8 mixtures [1].

3. EXPERIENCES WITH TWO TEST TRACKS PA 8 40% RA ON HIGHWAYS

3.1 Locations and origin RA

Based on the good experience in the lab, a test track was initially placed on the A9 near Amsterdam. In this track, with a surface area of 1000 m^2 and a length of 84 m, over 100 tons of PA 8 asphalt with 40% RA was processed. The positive results of this test track gave such confidence that on the A50 (Veghel-Oss) a larger track was constructed: 1.7 km length, in which over 1100 tons of asphalt were processed. For this track the RA of A2 was used: this is the material with the strongest ageing (penetration grade = 8). The composition of this RA forms the input for the recipe in the asphalt plant, according to the type test mixture.

3.2 Production, processing and quality control top-layer PA 8 with 40% RA

During the production of the material, the common Factory Production Controls were carried out, including determining the air voids content. In Table 3.1, the air voids content of the test section on the A50 is set against the measured water permeability (Becker measurement). The requirement for Becker measurements for Two-Layer PA is ≤ 17 seconds.

Table 3.1: Void ratio PA 8 (test and reference compartment)

Mixture code	Description	Void ratio (%) (Type Test)	Air voids content (Factory Production control)	Water permeability Becker time [s]
Top-layer 84307	Reference PA 8	25.4 %	25.3 %	7.4
Top-layer 84347	PA 8 with 40% RA	20.9 %	24.0 %	8.2

The produced PA 8 with RA is paved in the same manner as the reference PA 8 without RA; no differences were noticeable. In Table 3.2, the quality control of the construction process is included. In addition to these quality controls, also other functional properties like skid resistance, braking distance and noise reduction were measured, which were also found to meet the specifications. Also the resistance against ravelling in the paved mixture is measured, which is done by fulfilling RSAT tests on cores (Ø150 mm). Based on the test results, the PA 8 mixture with RA is equivalent to the reference mixture, see Table 3.3.

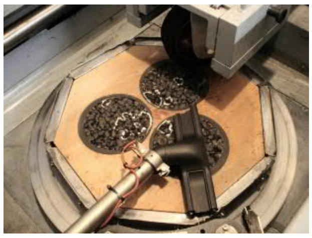
Table 3.2: Overview quality control of the constructed PA 8 with 40% RA (14 samples)

Sieve	Target composition	Composition			
[% m/m]	(Type Test)	Average result (μ)	St. dev. (s)	Min	Max
C 16*	100	100.0	0.0	100.0	100.0
C 11.2	100	99.8	0.4	98.8	100.0
C 8	93	91.7	2.1	88.0	94.7
C 5.6	39	42.7	5.4	33.0	50.0
2 mm	12	11.9	1.1	9.9	13.2
500 μm	9	9.1	1.1	7.2	10.3
180 μm	-	7.7	0.9	6.2	8.9
63 μm	5.0	5.92	0.5	5.1	6.5
Binder	5.4	5.21	0.1	5.0	5.4

* *In four of the 14 samples, the passing fraction through sieve C11,2 was smaller than 100%. In those cases, also the fraction passing sieve C16 was examined.*

Table 3.3: Results RSAT at cores

Mixture code	Description	Stone loss RSAT [gr.]	
		Average	Standard deviation
84307	Reference PA 8	11.3	3.0
84347	PA8 with 40% RA	11.5	2.3



4. FROST-THAW RESEARCH

At TNO-Delft, frost-thaw studies have been performed on some relevant mixture variants. The frost-thaw examination involves the exposure of test samples (cores Ø100 mm) to a temperature and humidity exchange protocol [4]. It is applied as a standard protocol in the Netherlands, particular to new PA variants. The lead time of the protocol is more than 3 months. Half of the test specimens underwent frost-thawing treatment (protocol V) and the other half was conditioned during that period (protocol I). For protocol V the conditioning time in water is 1000 hours, preceded by 30 minutes vacuum in water. Hereafter, –in accordance with NEN 2872– 24 cycles of 48 hours frost-thaw loads take place. During the thermal load the test pieces are placed in a mold. After the conditioning period, indirect tensile test (ITT) was performed on all specimens at a temperature of 5 °C according to NEN-en 12697-23. Figure 4.1 displays the frost-thaw protocol schematically, while Table 4.1 presents a summary of the results, which show that the frost resistance of the mixtures with RA is at least equivalent to the reference mixture.

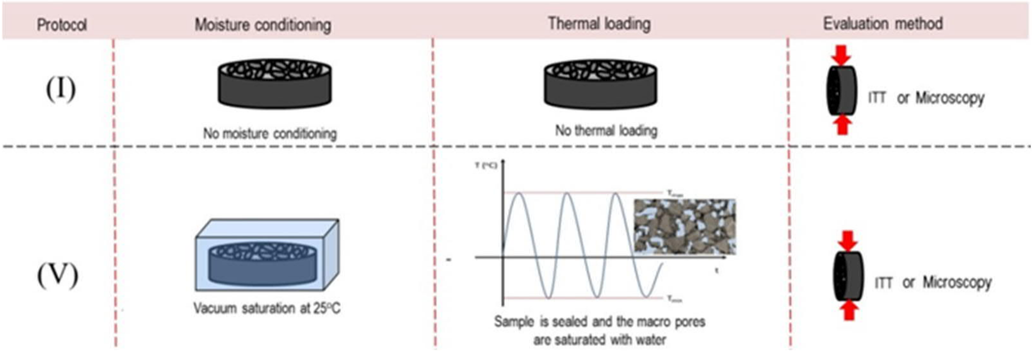


Figure 4.1: Frost-thaw protocol I and V

Table 4.1: Results Frost-thaw tests on Top Layer mixtures with and without RA

Mixture code	Description	Protocol	ITS Average	St.dev.	ITSR
	[-]	[-]	[N/mm²]	[N/mm²]	[%]
84307	Reference PA 8 top-layer without RA	Protocol I	1.48	0.13	66%
84307	Frost Thaw reference PA 8 top-layer	Protocol V	0.97	0.09	
84347b	Reference PA 8 top-layer with 40% A50 RA	Protocol I	1.53	0.08	69%
84347b	Frost thaw PA 8 top-layer with 40% A50 RA	Protocol V	1.05	0.08	
84347d	Reference top-layer with 40% A2 RA	Protocol I	1.62	0.08	67%
84347d	Frost thaw PA 8 top-layer with 40% A2 RA	Protocol V	1.08	0.07	

5. ADDITIONAL STUDIES ON THE BINDER

5.1 Homogeneity of bitumen layers around the minerals determined by means of peeling

The homogeneity of the binder layer around the stones in the recycling PA 8 mixtures is determined and compared with the reference PA 8 mixtures. This is done by peeling off the binder layer and examine the (in)homogeneity throughout this layer [5]. The study was carried out on the same mixtures as applied in the test tracks, so:
- 84307: top-layer PA 8; reference
- 84347: top-layer PA 8 with 40% RA.

5.1.1 Procedure peeling examination: extraction and recovery

By extracting the finished PA 8 product in an extraction device (rapid extraction by using asphalt analyzer) and tapping the extract solution directly from the beginning with fixed time intervals (0-1, 2-3, 3-5, 9-11 and 12-22 minutes), the gradient in the bitumen quality can be determined over the layer thickness. The outer bitumen comes off first and subsequently the bitumen that is deeper in the layer. Finally, the bitumen is released from the surface of the stone. For each test five points during the extraction period are analyzed. Two things are important:
- Sufficient material must be available per measuring point to be able to perform the test;
- The points must be as spaced as possible; so that an view can be formed over the entire thickness of the bitumen layer.

During the "peeling off" procedure extract samples are taken from minute: 0-1, 2-3, 3-5, 9-11 and 12-22. The later samples have been sampled over a longer period of time to gather sufficient material (the bitumen concentration is decreasing during time).

From all the extraction samples the bitumen is recovered. These binder samples have been investigated with two techniques: infrared determination (IR, "fingerprint") and gel permeation chromatography (GPC, determination of the molecular size).

After recovery the latest samples in the row, there was a relatively small amount bitumen left in the flask. This small amount is then spread over a relatively large surface in the flask and it must also be brought at a relatively high temperature to be poured out from the flask. This causes a considerable thermal load with an intensive oxygen contact (thin layer). This will cause some degree of ageing, which will be addressed in the discussion of the results.

5.1.2 Results FT-IR analysis

The IR analysis are visualized in Figure 5.1 (PA 8 reference without RA) and Figure 5.2 (new PA 8 mixture with 40% RA). In both graphs, the results of the recovered binder from the old RA material (blue) and the fresh new SBS bitumen (red) are included as a reference.

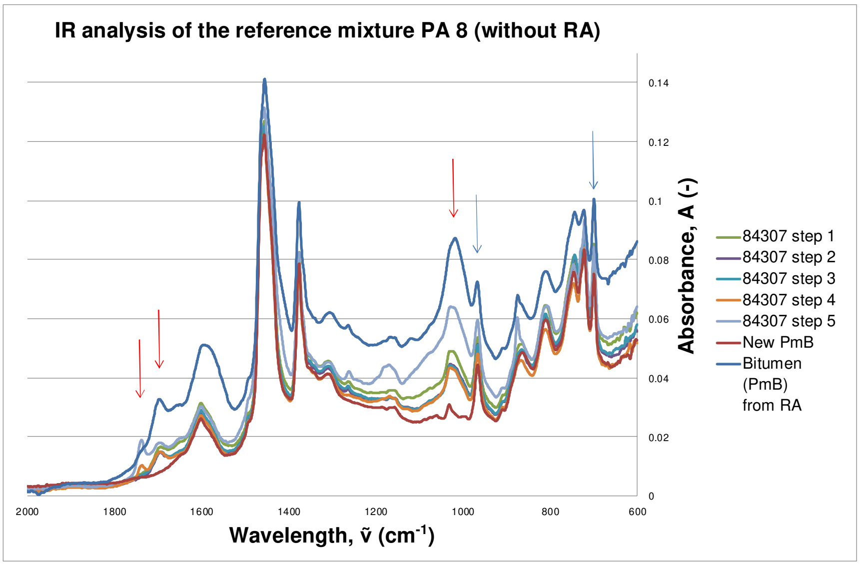


Figure 5.1: IR analyses of the peeling-off steps of the reference PA 8 mixture without RA

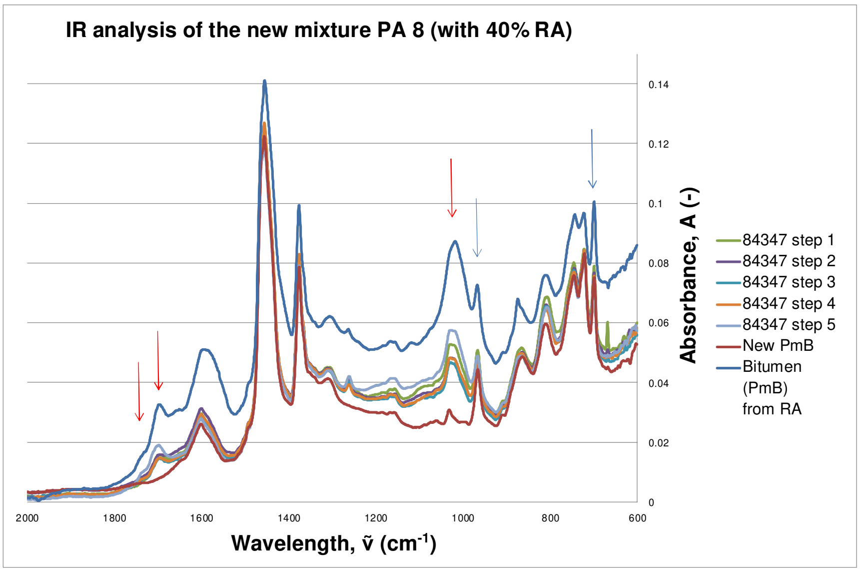


Figure 5.2: IR analyses of the peeling-off steps of the PA 8 mixture with RA

The IR analysis generates peaks in the frequency spectra that are characteristic for certain components in the binder. Some general peaks show the presence of hydrocarbons that are widely present in each bitumen, for example the two largest peaks around the wavelength of 1400 (cm^{-1}). In addition, there are some wavelength areas that indicate the ageing of the binder, such as around and just above the 1700 (cm^{-1}) (carbonyl compositions) and around 1000 (cm^{-1}) (sulfoxide). These areas are shown in the figures below with red arrows in the graphs. Furthermore, it is also evident that the SBS-modified compositions are concerned. In this case, two characteristic peaks are visible in the frequency spectrum: at 960 and 700 (cm^{-1}), these are shown in the figures with blue arrows.

It is clearly evident that those SBS peaks are both present in the old and the new binder at the exact same wavelength. In the combined binder from the end mixture with RA, these are therefore no longer separately distinguishable. At the ageing peaks (around 1000 and above 1700 (cm^{-1}); see the red arrows) it can be seen that the old binder has experienced an ageing process during service life, while the new binder did not.

There is, however, a second difference which must be involved in the interpretation: the old binder has experienced extraction and recovery, the new binder comes fresh from the can. Since no old binder is present in this mixture, the difference between the fresh PmB and the lines of (especially the first) peeling-off steps is the effect of production, processing, extraction and recovery. This difference is significant and important if the PA 8 mixture with RA is considered later on.

Furthermore, the fresh PmB in this reference mixture also shows segregation in the binder layer; the line of the first 4 peeling-off steps steadily shifts slightly to the bottom. Only at step 5, a clear shift can be observed, which again is to be traced back to the ageing of the small bitumen sample in the flask when recovering (very thin layer). In the IR analysis of the peeling-off steps from the PA 8 mixture with 40% RA (Figure 5.2), the same tendencies as in the reference PA 8 mixture can be observed: the line shifts down during the first four peeling steps and then upwards in the last peeling step. Also in this graph the references are added: 100% old and 100% new PmB.

Concerning the differences between the peeling steps, it is noted that the lines are not further apart than in the graph of the reference PA 8 mixture. The homogeneity in the binder layer around the stones is thus equivalent to the reference PA 8 mixture. Also, compared to the reference mixture, there are no strange peaks that could indicate pollution of the binder due to the previous function in asphalt.

The overall conclusion of the IR analysis on the peeling-off steps is, that the addition of the rejuvenator in combination with the production process (soaking process) creates a product that, in terms of homogeneity of the binder in the layer around the stones, can be seen as comparable with the reference PA 8 mixture.

5.1.3 GPC analysis

As an analysis method, also Gel Permeation Chromatography (GPC) is used. In this method, the molecular size distribution is determined in a sample which has been dissolved in THF (Tetrahydrofuran). As an indicator for the molecular mass distribution, different molecular mass values (M values) are used, namely: Mn, Mw, Mz and Mz + 1. Mn emphasizes the smaller molecules in the sample; Mw, Mz and Mz + 1 emphasize the larger molecules. In this paper it is sufficient to display the results with two characteristic indicators: Mn (small molecules) and Mz + 1 (large molecules).

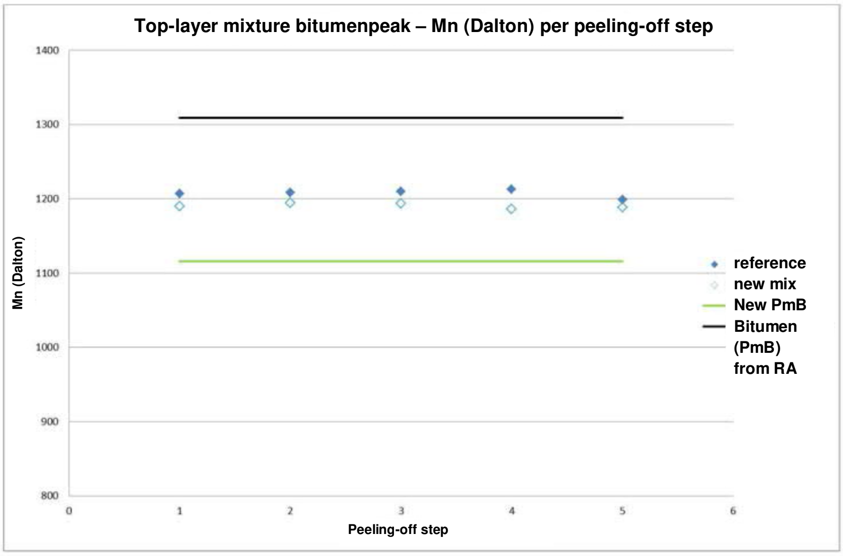


Figure 5.3: GPC analysis of the Peeling-off steps from the PA 8 mixture with RA (indicator Mn)

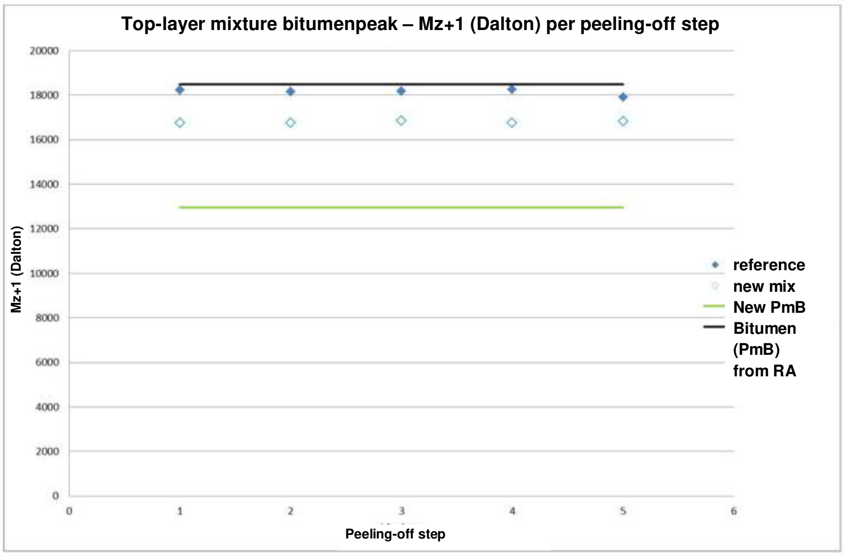


Figure 5.4: GPC analysis of the Peeling-off steps from the PA 8 mixture with RA (indicator Mz+1)

Figure 5.3 displays the Mn (Dalton) for the different peeling-off steps. The GPC results of new PmB and the recovered binder from the RA are also shown. The graph shows that the proportion of small molecules of the reference mixture and the mixture with RA is almost equal.

Figure 5.4 shows the indicator Mz + 1 per Peeling step. This emphasizes the largest molecules present in the bitumen sample. Again, the lines of the pure binders (new and old) have been added. The line from the RA mixture and that from the reference mixture are rather equal. Also for this indicator the uniformity over the thickness of the bitumen layer around the stones of both mixtures is comparable and good.

The above two graphs explain that the PA 8 mixture with RA has a homogeneity within the bituminous layer that is comparable and sometimes even better than the reference PA 8 mixture without RA. This indicates a good blending of the old bitumen from the RA with the new bitumen. Not least, the production process (soaking with a rejuvenator) will have led to this positive result.

5.2 Study of the PmB binder in PA 8 with 40% RA

5.2.1 Functionality of the composite PmB in the PA 8 mixture with RA

To look even deeper into the PmB binder, not only the "IR-fingerprint" but also the functional/mechanical behavior of the recycled bitumen should be investigated. This is done by means of DSR measurements.
Of the following variants the master curve is calculated on basis of a shift factor and DSR results:

1. Old, recovered PmB from the RA;
2. Old, recovered PmB mixed with the rejuvenator in the proportion as it is present in the finished product;
3. The complete composite binder as it is present in the final product;
4. 100% new SBS PmB

The proportions used are shown in Table 5.1; this are the proportions as they are present in the PA 8 mix with 40% RA. In Figure 5.5 the master curves of the four mixtures are plotted (G * at the frequency) at a reference temperature of 25°C. In the graph it is clearly visible that, starting from the old PmB the line moves more and more towards the new PmB. The master curves of the final product with RA and that from the reference mixture are almost equal. This research therefore shows that with the applied recycling technique also the functionality of the polymer bitumen is recovered.

Table 5.1: Ratios of binders in analyzed binder-mixtures

Blend	Mixture 1	Mixture 2	Mixture 3	Mixture 4
Old PmB from A2 - RA	100%	75.1%	25.2%	-
Rejuvenator	-	24.9%	8.3%	-
New PmB	-	-	66.5%	100%

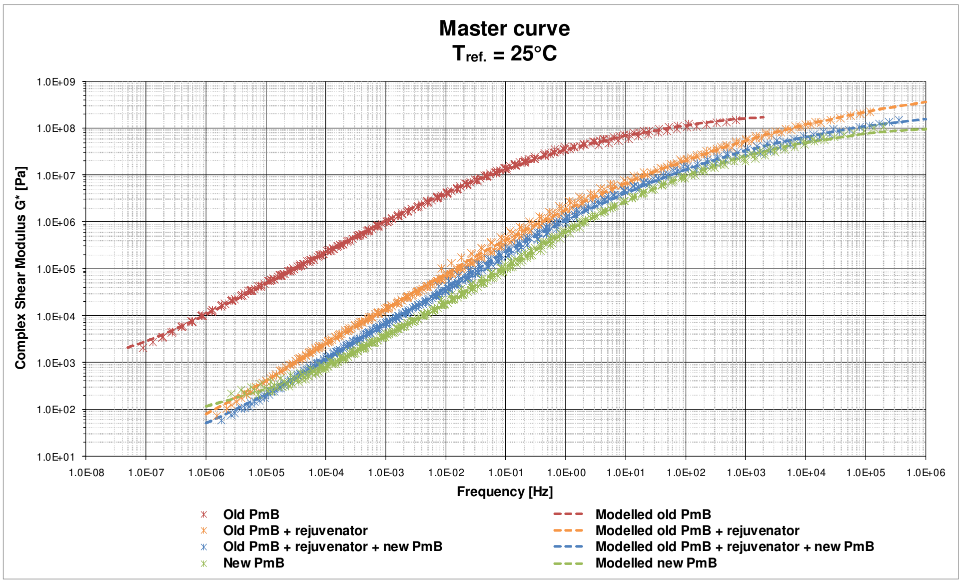


Figure 5.5: Master curves of the various variants at a reference temperature of 25°C

5.2.2 Ageing sensitivity of the compound PmB

In addition to the study of the viscoelastic properties of the various composite products and reference materials, the ageing sensitivity of the composite PmB has been investigated. For this purpose, mixtures 3 and 4 from Table 5.1 are compared with each other. The materials are first aged by RTFOT to simulate the short-term ageing effects from the production and processing, after which they are aged by PAV to mimic the effects of long-term ageing.

Figure 5.6 shows the master curves before and after ageing of the composite binder (old PmB + rejuvenator + new PmB, mixture 3) and the pure new PmB (mixture 4). For comparison, also the curve of the pure old PmB (from the RA) is displayed. The graph clearly shows that the composite binder, also after ageing, behaves similar with the aged pure PmB. On this basis, it may be assumed that the composite binder behaves in an equivalent manner with the new binder in terms of ageing.

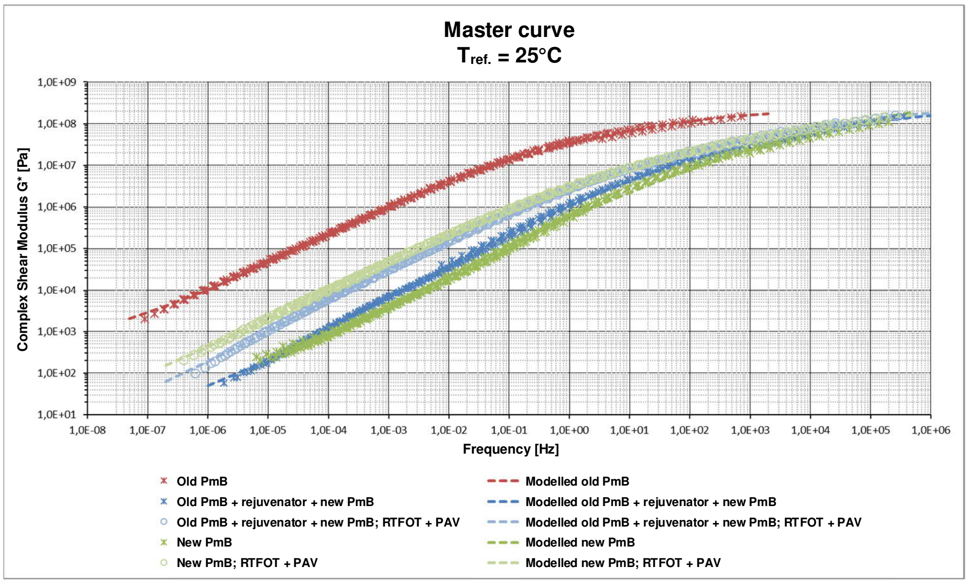


Figure 5.6: Master curves of aged bitumen samples

6. PRACTICAL RELEVANCE

The new recycling system has been widely used since its development in 2016. In total, 13.360 tons of Porous Asphalt PA 8 with 40% RA have already been produced with 40% reuse, which has been applied in 5 jobs at 70 km highway lane. Figure 6.1 shows the application and Figure 6.2 shows the condition of a PA 8 with 40% RA after it has been used for 3 years. The experiences with production and laying of this product are positive and the end result meets all the functional requirements that are set for new PA surface layers. It has already made a major contribution to the reduction of CO_2 and an important step has therefore been made towards the goal of 100% circularity within the asphalt chain.

Figure 6.1: Application of the developed material at the Highway A9 near Amsterdam

Figure 6.2: Section of the PA 8 with 40% RA in the A50 near Veghel; realized in August 2016; photo from April 2019

7. CONCLUSIONS AND RECOMMENDATIONS

On the basis of the research carried out, it can be concluded that with the applied 2-phase innovative mixing system, it is possible to produce well-acting Porous Asphalt 8 mixtures with modified bitumen with reuse of 40% old PmB asphalt. The first mixing phase (soaking with an appropriated rejuvenator as pointed out in Section 2.3) is essential. By this production method the PmB binder in the old material is reactivated and contributes to the properties of the end product, making it qualitatively and functionally equivalent to a completely new PA 8 mixture with PmB.
Some specific measures need to be taken. For instance:

- The old PA 8 layer has to be milled selectively, without material from the underlying layer.
- From the milling material the fraction < 4 mm has to be removed by means of sieving.
- In the mixture-design a suitable rejuvenator and a new PmB has to be chosen. The examination-method to determine with which quantities this components should be dosed, is also important.

The resistance to ravelling of the PA 8 layer with RA is minimally equivalent to that of the standard PA 8 without RA. Water permeability, noise reduction and frost-thaw resistance also meet the requirements for PA 8.
From advanced research on the homogeneity and quality of the binder layer to the coarse aggregate in the end product the following conclusions can be drawn:

- The composite binder is homogenous in the shell around the aggregates and the quality is comparable with new PA with PmB.
- The composite binder acts in the DSR in accordance with a new PmB.
- The ageing sensitivity of the composite binder is also corresponding with new PmB.

The Dutch Government (Rijkswaterstaat) has included the PA 8 test sections in the monitoring program that provides for long-term monitoring to assess how the mixture also proves itself in practice. Now, three years after realisation no difference can be determined. Thanks to the positive results, this process is completely released by the Dutch Government; for new jobs where virgin PA8 is requested, Heijmans is allowed to apply the new developed mix with 40% RA. Already large-scale applications have been carried out.
The present research gives handles to develop a protocol, which can be used in advance to check whether the existing PmB in RA can be reactivated by a rejuvenator and mixed with new PmB into a functional and high quality end product.

References:

[1] CROW, 2014, *Standaard RAW Bepalingen 2015* [Standaard RAW regulations 2015, *in Dutch*].
[2] CEDR, 18-12-2017, *DRaT – Development of the Ravelling Test*, Proposals for revision of standard PR CEN/TS 12697-50, version 1.2, CEDR Transnational Road Research Programme, Call 2014: Asset Management and Maintenance, available online: http://dratproject.eu/wp-content/uploads/2018/02/DRaT-D9-Proposals-for-revision-of-standard.pdf
[3] J. Hartjes and J. Voskuilen, 2008, *Classificatie van asfaltmengsels met de RSAT proef* [Classification of asphalt mixtures with the RSAT test, *in Dutch*], CROW Infradagen 2008.
[4] Scarpas, T. et al., 2012, *Frost damage research*, InfraQuest 2012-64.
[5] G. van Bochove, M.M. Willemsen, D. van Vliet and J. Voskuilen, 2014, *Afpelonderzoek – bepaling homogeniteit bindmiddel* [Peeling-off Examination – Determination homogeneity binder of PA with RAP, *in Dutch*], CROW Infradagen 2014