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Recycling of Porous Asphalt Mixtures with PMB to Increase Sustainable Use of Non-renewable Materials

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Abstract: In the Netherlands, porous asphalt (PA) is extensively used as a surfacing layer on motorways to reduce the noise level. Due to the high voids content, the binder in porous asphalt mixture ages strongly and normally PA has a service life around 7 to 12 years. To design a PA mixture by using part reclaimed-PA mixture containing polymer modified bitumen (PMB) is a big challenge for this type of mixture. The involvement of PMB makes it even more complicated. In this study, an "old" SBS polymer modified bitumen (PMB) obtained from reclaimed porous asphalt (RA) was blended with two virgin binders, one normal penetration grade bitumen and one soft PMB at two ratios. The blending effect was investigated in terms of the rheological properties in order to investigate the potential and the possibilities for recycling porous asphalt with PMB into a new PA mixture with similar or even the same quality as the virgin PA. The results indicate that both the logPen. Model and the S.P. model can be used to predict the full blending effect for PMB RA plus virgin Pen. grade binders and PMB RA plus virgin PMB binders. It should be noted that the logPen. Model is at logarithmic scale and the S.P. model at linear scale. Although recycling PA mixture may benefit more from the addition of virgin PMB because it improves high-temperature permanent deformation resistance, low-temperature cracking and drainage resistance during transportation, it will also consume more energy due to the higher mixing and compaction temperatures for blended binders.

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***Key words:** Polymer modified bitumen; Porous asphalt; Recycling.*

Introduction

Reclaimed asphalt (RA), also called Recycling Asphalt Pavement (RAP) is used extensively all over the world now. The oil crisis in 1973 stimulated efforts to find alternative methods and materials to produce asphalt mixtures. One possibility was of course the recycling of old asphalt mixtures. Many projects in the USA, Netherlands, Japan and Great Britain were started with the ambition to develop the best process to reuse RA. Local economic and political situations were very important for the directions chosen in these countries. The economical benefits of using RA are in most cases an advantage, since RA has a relatively low cost price compared to virgin materials. For example, the investment in parallel drums in the Netherlands was no problem at all in the decision to scale up the use of RA. Hot reuse of RA makes it possible to replace part of the expensive virgin bitumen by the aged bitumen in the RA. This has resulted in a high level recycling application. Of course the question arises if reuse of RA in hot mix will influence the quality of the end product because asphalt concrete with RA will have to fulfill the same functional requirements in the new CE-marking system and standards at the same high application level.

There is only limited information available on the influence of addition of RA to a mixture on the properties. In the Netherlands a lot of information is available on initial mechanical properties of mixtures with high percentages of RA (mostly 50%), but no record is really available on the service life. In Flanders (Belgium) RA is used in most asphalt mixtures for base layers, without a scientific validation of the influence of RA on the durability of the mixtures in situ [1]. In 2009, the total production of hot mix asphalt mixtures in Belgium was estimated at 4700000 tons of which 44% contained RA. Yearly about 1300000 tons RA is released for recycling. 57% of this RA is used for hot mix recycling (741000 ton). Based on these figures, 16% of the mixtures contain RA, which is rather low. 52 % of the total asphalt production was used for top layer mixtures and 48 % for base layers. Up to 2010, in dense asphalt concrete up to 50% recycling is allowed. As from 2011, no recycling is allowed in surface layers. For base layers (dense asphalt concrete according to EN13108-1), all mixtures are allowed to contain RA up to 50%. It is often questioned if the use of RA can influence the quality of the mixture in a negative way. One thing is clear: the production process is becoming much more complicated when using RA. A composite material with often quite some variability in composition is added instead to separately added components.

Recycling with low amounts of RA (up to 20%) was for many years common practice and quite simple, because it is mostly done with cold addition of the RA in the pug mill for a batch plant mixer or halfway the drum mixer. However, recycling with high amounts of RA (50% and more) and producing high quality asphalt mixture is a technological challenge. RA contains aged bitumen, has not always a homogeneous composition and contains impurities in a number of cases. It is then very difficult to predict the material properties after production and compaction. The same holds for the quality control of mixtures with RA. The volumetric parameters of the mixture can change and probably show larger deviations than normal. The composed binder contains partly aged (oxidized)

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bitumen and the ratio with the virgin bitumen is based on the so called log penetration rule. The angularity of the aggregates is not only dependent of the primary aggregates; the compactibility can be quite different with higher percentages of RA. Also the logistics of a RA materials stream is a complex and costly process.

In the Netherlands almost all RA is reused in hot mix asphalt mixture. In 2007 approximately 3.5 million tons of RA was used on a total hot mix production of 10 million tons [2]. In the Netherlands almost all 40 asphalt plants have the possibility to preheat the RA. Because of the fact that almost all plants are batch plants, a parallel drum is used to preheat the RA to a maximum of 130 C, before it is added in the pug mill. In this way all Dutch manufactures produce 50% RA in hot mix asphalt mixtures, when allowed. The amount of RA and the requirements to use them are well specified in the Dutch standards (RAW). This standard allows for most mixtures to add up to 50 % of RA to the hot mixture to be produced. Assuming that almost all mixtures were produced with 50% RA, approximately 6 million tons of hot mixtures were produced with 50% RA in 2007.

Porous asphalt (PA) mixtures are extensively used in the Netherlands in the surfacing layer on motorways to reduce the noise level produced by car and truck tyres at speeds higher than 50 km/h [3]. In 2007, approximately 70% of the main road network was surfaced with porous asphalt and the coverage is still increasing. Due to the high voids, the binder in the porous asphalt mixture gets aged much faster than the binder in dense mixtures; a PA mixture normally has a shorter service life than a dense mixture. Higher quality materials are often used for this surface layer, for example basalt as aggregates and polymer modified bitumen (PMB) as binder. Therefore, it is necessary to find the potentials and possibilities of recycling polymer modified porous asphalt into new high quality surface layers with hot mix recycling, although at present it is forbidden to use RA in porous asphalt surface layers in the Netherlands.

Recycling of RA with PMB is different from recycling with only penetration grade aged binder. It is questioned if the logPen. model can be applied to predict the properties of the blended binder when PMB is used in the RA and the added binder. Once more, PMB can be more stiff compared to Pen. grade bitumen at normal and/or elevated temperatures, therefore the recycling method needs to be adjusted. The adjustment has to be made with respect to the type of addition that is needed to create an asphalt mix and with respect to the temperature that is needed during mixing. In this study, an “old” PMB from reclaimed porous asphalt was extracted and blended with two virgin binders, a normal Pen. grade bitumen and a soft PMB, each at two ratios. The effect of blending was investigated in terms of the rheological properties to investigate the potential and the possibilities for recycling porous asphalt with PMB from surface layers into new surface layers.

Materials and Tests

A porous asphalt mixture (PA 8/4) was reclaimed from the top layer of a 7 year old double layer porous asphalt system. The section is located between Den Bosch and Eindhoven on Expressway A2 in the Netherlands. The SBS RA binder was extracted by solving in dichloromethane followed by rotary evaporation according to EN 12697-1 and EN 12697-3 [4, 5]. A Pen grade bitumen with paving grade 70/100 (Pen. 70/100) was offered by Kuwait Petroleum (Nederland) B.V., and a soft PMB by mixing 10% of D0243 SBS in B160/220 bitumen, produced by Kraton Polymers Nederland BV. The RA binder was blended with the virgin bitumens at two ratios, 15% and 40% by weight. A Silverson L5M high shear mixer was used to blend the combined binder with a mass of about 500 grams at a rotation speed range between 4000 and 7000 rpm for 10 mins. The blending temperature was set at 145±5 °C.

Table 1. Configuration and Input Parameters of DSR.

Device	Diameter, R [mm]	Temperature [ºC]	Gap, [mm]	Frequency [Hz]
DSR	25	25, 30, 40, 50, 60, 70,	1	0.01 ~ 10
	8	-5, 5, 15, 25, 30	2	0.01 ~ 10

The penetration and softening point (R&B) were measured according to EU specifications (EN 1426 for penetration and EN1427 for softening point) [6, 7]. Softening points above 80 °C were determined in a glycerol bath. Dynamic frequency sweep tests by using a dynamic shear rheometer (DSR) AR 2000ex were done according to EU specification, EN 14770 [8]. Configuration and input test parameters are given in Table 1. With respect to these two methods, the viscosity needs to be determined at the temperatures of 135 °C, 150°C and 180°C. According to EU specification (EN 13702) [9], a shear rate of 500 s-1 was used to characterize the viscosity at these three temperatures by using a cone/plate rheometer on the DSR. The cone angle is 1°, and the plate diameter is 25 mm. A shear rate sweep (from 0.1 s-1 to 500 s-1) was performed at 150 °C.

Results and Discussion

Penetration and Softening Points

Fig. 1 and 2 show the penetration (Pen.) and softening point (S.P.) results for two binder groups, RA+Pen70/100 and RA+PMB. As indicated, the penetration increases gradually with the increase of virgin binder content after mixing with virgin Pen. 70/100 and with PMB. The penetration of 31×0.1mm (blended binder of 40%RA+Pen.70/100) is still very low if it was used for the practical design of the mixture. For the purpose of obtaining correlations as precise as possible, the softening point determinations have not been rounded off in accordance with EN 1427 (nearest 0.2 ºC in water below 80 ºC and nearest 0.5 ºC in glycerine above 80 ºC). By mixing with virgin Pen. grade binder, the S.P. of the mixed binder will decrease; however, binders in the RA+PMB group have similar S.P. because RA binder and PMB have a very comparable S.P. value.

The standard EN 13108-7 gives the logPen. model and the linear S.P. model to predict the Pen. value and S.P. value of a binder mixed with RA [10]. These formulas are given in principle for standard penetration grade bitumen. They are given below:

$$\log \mathrm{Pen}_{mix} = a \log \mathrm{Pen}_1 + b \log \mathrm{Pen}_2 \quad (1)$$

$$T_{S.P.\ mix} = a\, T_{S.P.\ 1} + b\, T_{S.P.\ 2} \quad (2)$$

where,

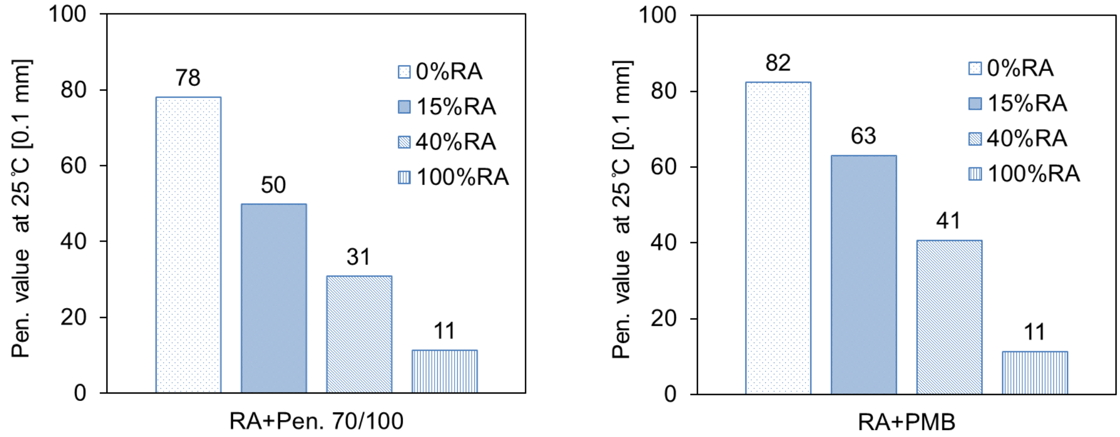


Fig. 1. Penetration Values at 25 °C for Binder Groups of RA+Pen. 70/100 (Left) and RA+PMB (Right).

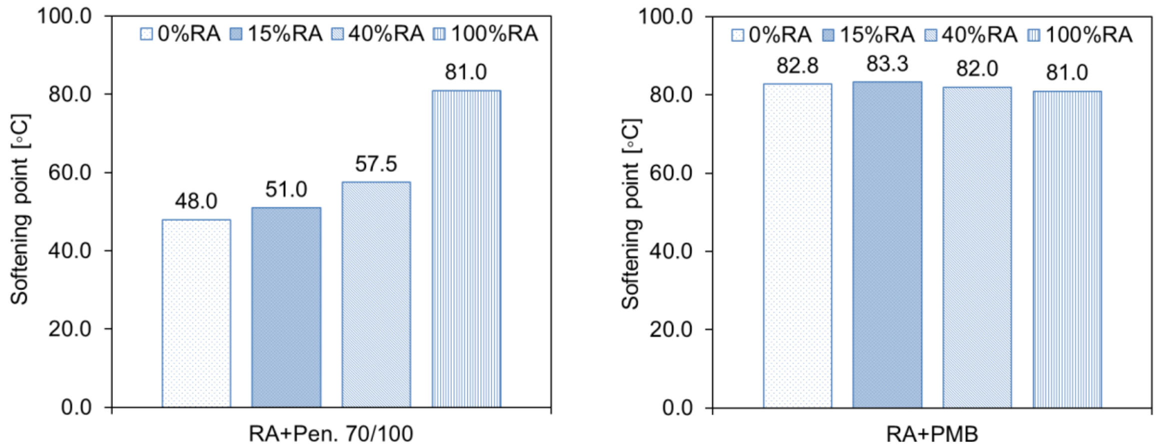


Fig. 2. Softening Point for Binder Groups of RA+Pen. 70/100 (left) and RA+PMB (Right).

Pen_{mix} is the calculated penetration of the binder in the mixture containing reclaimed asphalt;
Pen_1 is the penetration of the binder recovered from the reclaimed asphalt;
Pen_2 is the penetration of the added binder;
$T_{S.P.\ mix}$ is the calculated softening point of the binder in the mixture containing reclaimed asphalt;
$T_{S.P.\ 1}$ is the softening point of the binder recovered from the reclaimed asphalt;
$T_{S.P.\ 2}$ is the softening point of the added binder;
a and b are the portions by mass of binder from the reclaimed asphalt (a) and from the added binder (b) in the mixture; $a + b = 1$.

Figs. 3 and 4 show the comparison of test results with the logPen. model and the S.P. model at different RA contents. It indicated that both the logPen. model and the S.P. model were useful to predict the effect of recycling on a blended binder in terms of PMB RA plus virgin Pen. grade binder and PMB RA plus virgin PMB binder. Although the simulations are more comparable to the tested results when using the logPen. model, it is hard to say that the logPen. model is more precise to predict rheological properties of blended binders than the S.P. model because it is based on a logarithmic scale and the S.P. model on a linear one.

Viscosity Results

Fig. 5 shows the viscosity results at a shear rate of 500/s for these two binder groups at 135ºC, 150 ºC and 180 ºC measured with the cone/plate rheometer. As indicated, the viscosity for all binders decreases with the increase of temperature. The RA binders have a higher viscosity at the same temperature. For the virgin binders, PMB has a higher viscosity than the virgin Pen. grade bitumen at these three temperatures. After mixing, the viscosity of the blended binder is between those of the RA and the virgin binder and gradually becomes very close to the viscosity of virgin binder as the temperature increases to 180 ºC.

Based on the viscosity results, the recommended laboratory-mixing and compaction-temperatures are given in Table 2, for a viscosity range between 0.15 to 0.19 Pa.s and 0.25 to 0.31 Pa.s, respectively. As shown, mixing temperatures of RA+PMB binders are higher than 180 °C due to that the viscosity at 180 °C is slightly out of the recommended range. Meanwhile, higher compaction temperature is also needed. This means that in recycling more energy will be consumed for the manufacture and construction of mixture with virgin PMB than with Pen. grade bitumen.

To get a better understanding of the viscous behaviour of binders, a shear rate sweep was performed at 150 ºC with the cone/plate rheometer and the results are shown in Fig. 6. As shown in the left part of the figure, the three binders with 0%, 15% and 40% RA behave practically like a Newtonian liquid because the viscosity

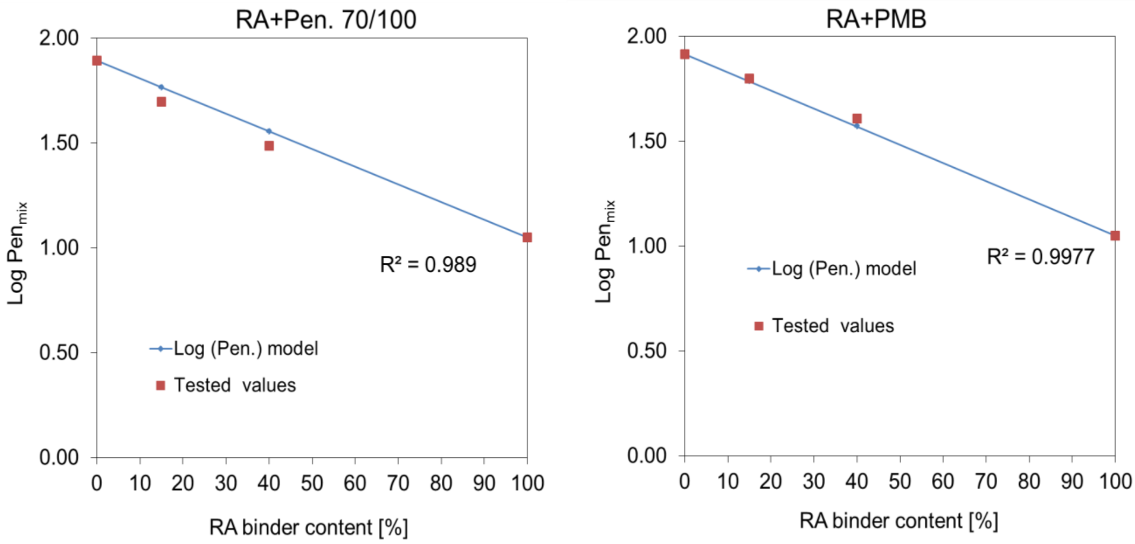


Fig. 3. Relation between Pen. Value at 25 ºC and RA Binder Content for Binder Groups of RA+Pen. 70/100 (Left) and RA+PMB (Right).

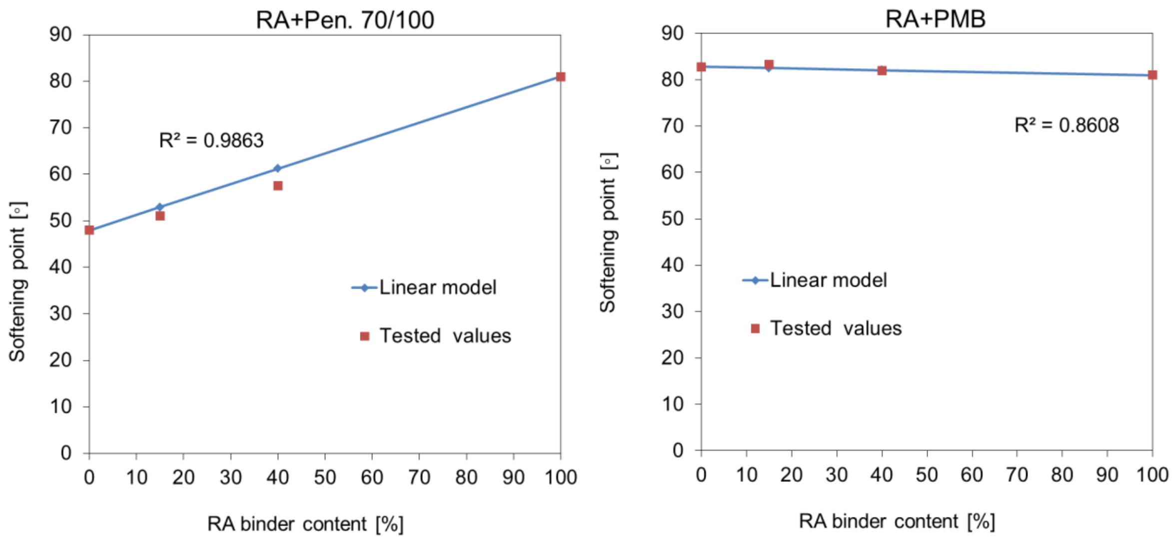


Fig. 4. Relation between S.P. Value and RA Binder Content for Binder Groups of RA+Pen. 70/100 (Left) and RA+PMB (Right).

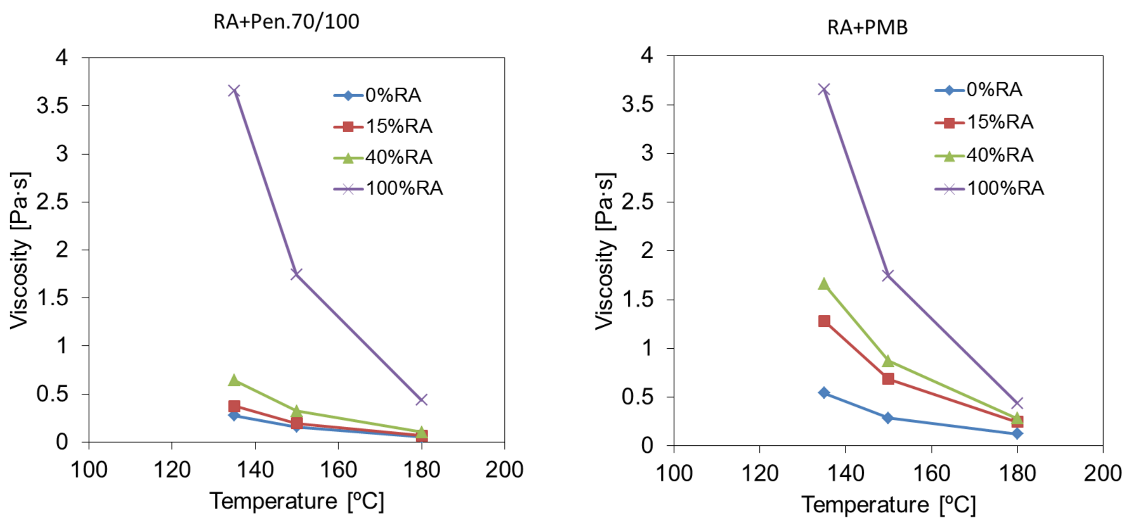
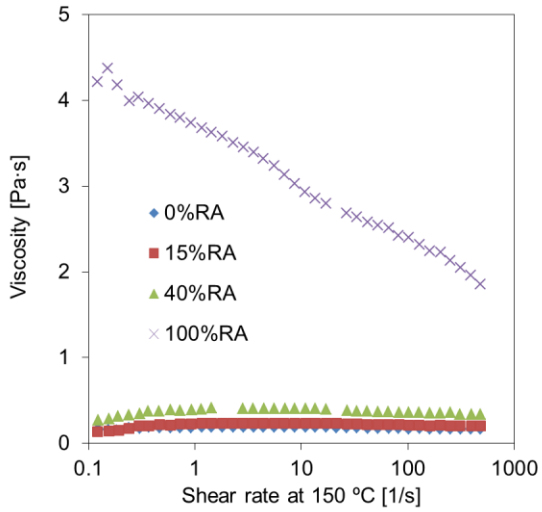


Fig. 5. Viscosity at a Shear Rate 500/s and at Three Temperatures for Binder Groups of RA+Pen. 70/100 (Left) and RA+PMB (Right), Measured with the Cone/plate Rheometer.

Table 2. Recommended Mixing and Compaction Temperatures for Practice.

	Mixing Temperature [°C]		Compaction Temperature [°C]	
Binders	Max.(0.15 Pa.s)	Min. (0.19 Pa.s)	Max. (0.25 Pa.s)	Min. (0.31 Pa.s)
RA+Pen.70/100	155	145	140	130
Binder with 15%RA	160	150	145	140
Binder with 40%RA	175	170	160	150
RA+PMB	175	170	160	150
Binder with 15%RA	>180	>180	180	175
Binder with 40%RA	>180	>180	185	178



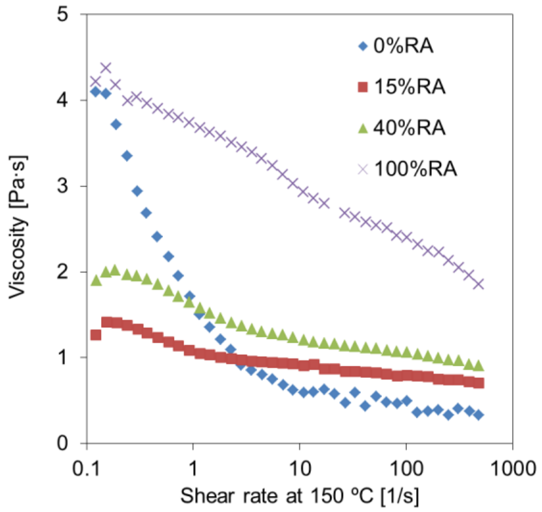


Fig. 6. Viscosity at 150 ºC as Function of the Shear Rate Measured with the Cone/plate Rheometer, for Binder Groups of RA+Pen. 70/100 (Left) and RA+PMB (Right), Measured with the Cone/plate Rheometer.

is independent of the shear rate; however, the viscosity of the 100%RA binder decreases continuously by increasing the shear rate from 0.1 and 500 s-1, which means its viscosity is shear rate dependent. Pure PMB also shows a shear thinning behaviour at low shear rate and gradually shows Newtonian behaviour above a shear rate of 10 s-1 (the right part of Fig. 6). SBS modified bitumen often shows shear thinning behaviour due to the orientation effect of SBS molecules at increasing shear rate. For PMB binders with 15% and 40% RA, this behaviour is still clear to see, but much less pronounced than for the pure PMB binder. The reason could be that the preparation process with high shear mixing decreases the phase size of SBS and makes it easier to orient when applied with a shear rate. A higher viscosity at low shear rate indicates good drainage resistance of bitumen. Therefore, the addition of virgin SBS modified bitumen can improve drainage characteristics of RA mixtures, a feature especially important for porous asphalt.

Master Curves

Fig. 7 and 8 show master curves of the complex shear modulus (G*) and phase angle (δ) at a reference temperature of 25°C for RA+Pen.70/100 and RA+PMB binder groups. Pure RA has a higher G* and a lower δ than other binders at the same reduced frequency. Some influence of the SBS modification on the RA binder can still be observed from the phase angle plateau at a frequency range between 10-1 and 10-4 Hz. Compared to the RA binder, the virgin Pen. 70/100 binder is less stiff (Fig. 7). For example, there is a more than 2 orders of magnitude difference in G* at a low frequency around 10-5 Hz between them. After blending, the binder with 15%RA behaves still like a Pen. grade bitumen, with a higher G* and lower δ than pure Pen. 70/100. For the binder with 40% RA, a small influence of the SBS modification in the RA can be observed on the master curve of δ.

In the RA+PMB group, virgin PMB behaves as a typical polymer modified binder (Fig. 8). It has a higher δ above the frequency of 10-1Hz, but a sharp decline in δ at reduced frequencies lower than 10-2 Hz. These characteristics indicate a good resistance of the binder to high-temperature permanent deformation and probably low-temperature cracking. After blending, the binder with 15% RA exhibits a very similar G* master curve compared to the pure PMB, but a small change in δ can be observed. For the binder with 40%RA, the master curves, especially for the phase angle, seem more like those of pure RA. This indicates that the RA binder start to dominate the rheological properties of the blended binder at a higher RA content, which as far as can be measured with master curves.

Saal and Labout found that, for both unmodified and modified bitumens, the penetration test correlates well with the stiffness of bitumen as measured with the DSR, at the same temperature (25ºC) and at a frequency of 0.4 Hz [11]. In rheological terms, a good correlation has been identified between $\log(G^*_{04Hz;\ 25^{\circ}C\ ;\ [MPa]})$ and $\log(G^*_{04Hz;\ 25^{\circ}C\ ;\ [dmm]})$. The correlation can be written as a linear equation:

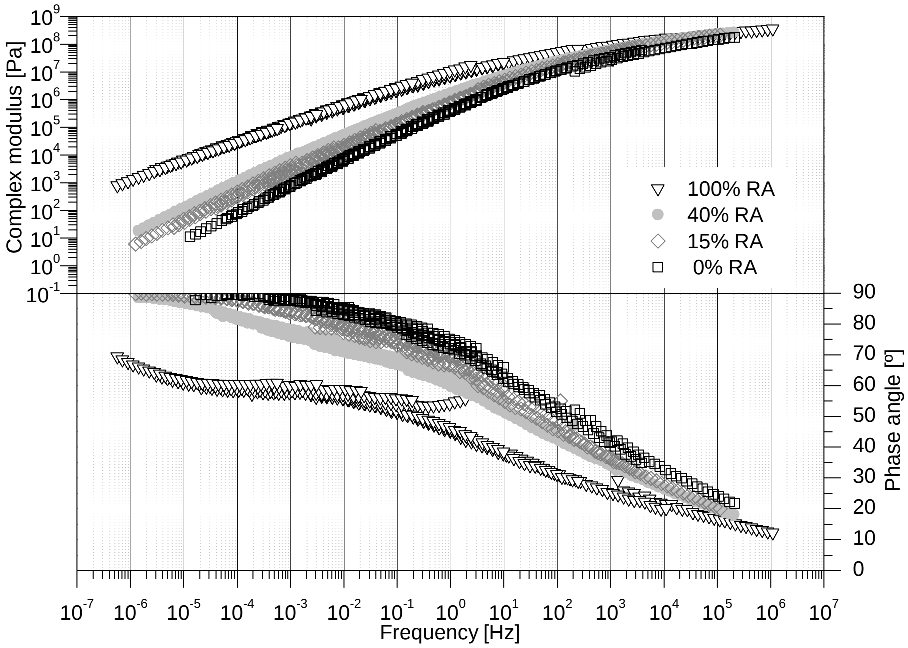


Fig. 7. Master Curves of the Complex Shear Modulus and Phase Angle for Binders in the RA+Pen. 70/100 Group at a Reference Temperature of 25°C.

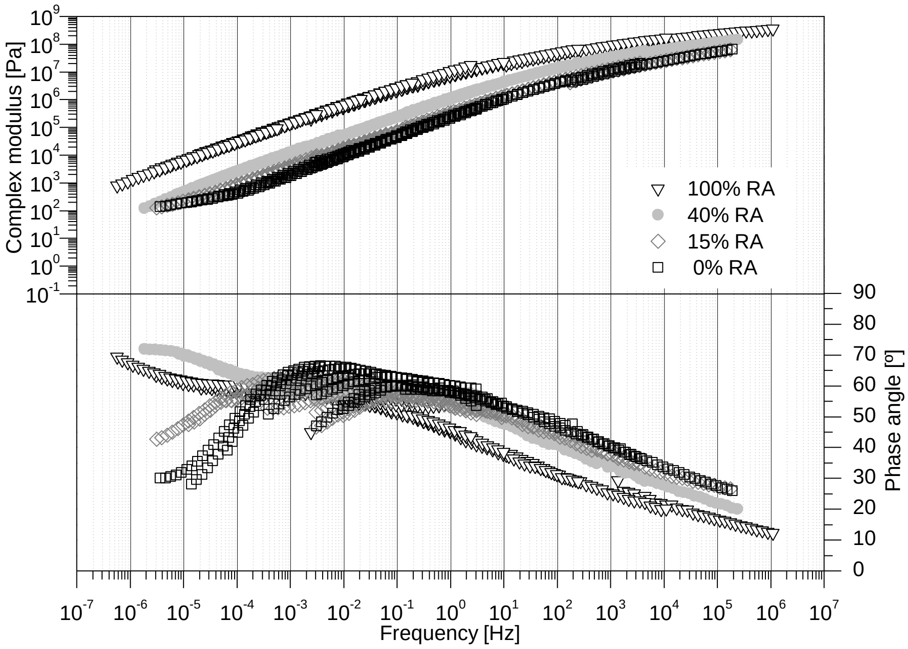


Fig. 8. Master Curves of the Complex Modulus and Phase Angle for Binders in the RA+PMB Group at a Reference Temperature of 25°C.

$$\log(G^*_{04Hz;\ 25°C\ ;\ [MPa]}) = 2.923 - 1.9\log(Pen._{25°C;[dmm]}) \quad (3)$$

In this study, the correlation between the results obtained from a DSR and penetration was determined and expressed as a linear equation (Fig. 9):

$$\log(G^*_{04Hz;\ 25°C\ ;\ [MPa]}) = 2.5812 - 1.797\log(Pen._{25°C;[dmm]}) \quad (4)$$

This equation compares very well with the previously relation found by Saal and Labout. It indicates that it is possible to use $\log(G^*_{04Hz;\ 25°C\ ;\ [MPa]})$ to predict the penetration of an RA binder if not sufficient material can be recovered for the penetration test.

Summary

A PMB RA binder was extracted and recovered from the top layer of double porous asphalt. The recovered PMB binder shows some residual properties of polymer modification. Although recycling of PMB RA is different from Pen. grade RA bitumen, the results

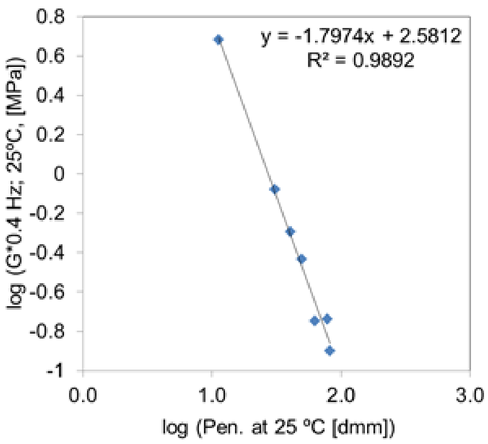


Fig. 9. Correlation between the Complex Modulus at 25 ºC and 0.4 Hz and Pen. Value.

indicate that both the logPen. model and the S.P. model can be used to predict the blending effect for PMB RA plus virgin Pen. grade binders and PMB RA plus virgin PMB binders. It should be noted that the logPen. model is at a logarithmic scale and the S.P. model at a linear scale. Although recycling of porous asphalt mixture may benefit more from the addition of virgin PMB for elevated-temperature permanent deformation, low-temperature cracking and drainage resistance during the transportation, it can consume more energy due to the higher mixing and compaction temperatures for blended binders.

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