Evaluation of the effect of recycled roof membrane on asphalt mixtures performance properties.

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Submission Date: July 30, 2012

Word count: 3689 words + 9 Figures (2250 words) + 4 Tables (1000 words)/
Total word count: 6939 words

A paper submitted for presentation and publication at
Transport Research Board 92nd annual meeting
January 13-17, 2013
Washington, D.C.

ABSTRACT

This paper examines the effect of replacing part of the virgin binder with recycled roof membrane on the performance of hot mix asphalt mixtures with high percentages of recycled asphalt (RAP). The use of recycled roof membranes influences the asphalt mixture properties. In this study the influence of replacement of virgin binder by the binder in recycled roof membranes (GRM-50) on the performance properties of surface and base course asphalt mixtures with high RAP contents evaluated. Functional mixture properties like stiffness, fatigue and permanent deformation were determined to evaluate the performance. In addition to mixture properties also the properties of the recovered binders of these mixtures were determined. Both empirical and fundamental binder properties of the recovered binders were determined using penetration, ring and ball, and Dynamic Shear Rheometer (DSR) tests. The DSR results show that the recovered binder from mixtures containing recycled roof membrane (GRM-50) has significantly higher complex shear modulus G* values especially at high temperature (low frequency). They also show a lower phase angle δ over a wide range of frequency and temperature compared to recovered binders from mixtures with only RAP. In line with the binder test results, the mixture tests clearly show that replacement of part of the virgin bitumen in the RAP mixture with recycled roof membrane increases the mixture dynamic stiffness, fatigue life and resistance to permanent deformation.

INTRODUCTION

The production of asphalt mixtures with different types of waste and secondary materials is increasing continuously due to technical, economic and environmental reasons. One of the waste materials used more recently in the asphalt industry is the binder from recycled roof sheet membranes to replace part of the virgin binder in the mixture. The recycled roof membrane used as roof covering or water proofing layer whose primary function is the exclusion of water. The addition of recycled roof membranes on asphalt mixture changes the strength properties of the asphalt mixture and affects its performance and durability [1-2]. The recycled roof membrane considered in this study contains highly polymer modified APP (Atactic Polypropylene) binder. The polymer in the modified binder is a well known thermoplastic (plastomer). The modified binder provides properties such as improved resistance to cracking at low temperature due to the binder flexibility, improved resistance to permanent deformation at high temperature and improved stiffness and fatigue life at intermediate temperatures. This can result in a significant contribution to the durability of the mixture in the road. Possible benefits include reduced maintenance cost and reduced disruption of traffic. In addition to the improvement of the performance properties of the mixture, the recycled roof membrane considerably reduces the cost of the asphalt mixture by replacing part of the new binder content in the mixture. Due to the high binder content of the recycled roof membrane, which is 50% by mass (m/m), savings up to 35% new binder in the mixture can be achieved.

MATERIAL AND TEST PLAN

Two types of dense graded asphalt concrete mixtures (surface and base layers) were prepared in accordance with the Dutch specifications. In the Netherlands it is normal to add high amounts of RAP to surface and base course mixtures. The surface course mixtures have a maximum aggregate size of 11 and 16 mm and contain 30% of RAP. The base course mixtures have a maximum aggregate size of 22 mm and contain 50% of RAP. 3% of GRM-50 was added to the surface mixtures with 30% RAP. 3.2% GRM–50 was added to the base mixtures with 50% RAP

Materials

Virgin materials

In this research crushed Norwegian granite aggregate, 70/100 penetration grade virgin binder was used for both surface and base course mixtures,Wigras 40K filler (factory produced filler which contains calcium hydroxide content of 5-15% by mass (m/m) and has Rigden void 42 and bitumen number 46). Two types of sand namely natural river sand 0-2 mm for the base course mixtures and crushed sand 0-2 mm for the surface course mixtures were used. One type of 70/100 virgin binder was used in this research, the binder has penetration value 82 (0.1 mm) at 25°C and softening point of 46 °C.

Recycled material (RAP and recycled roof membrane)

Two types of RAP were used in this research, one type for the base course mixtures and another type for the surface course mixtures. The grading of the RAP used for base course mixtures ranges between 0-20 mm nominal sizes which were obtained through the process of milling the base course asphalt layer. In order to get good homogeneity, the RAP was sieved and crushed after the milling process. In the same way, the RAP material used for surface course mixtures was obtained from the milling of surface course layers and crushed and sieved to nominal size

0-16 mm. The properties of the binder in the RAP and the gradation of the RAP aggregate was determined following the standard extraction and sieving procedure (NEN-EN 12697-1) and methylene dichloride was used as a solvent. A recycled roof membrane with highly polymer modified binder GRM-50 (a Dutch abbreviation for crushed roof membrane with 50% by mass (m/m) highly APP polymer modified bitumen, 20% by mass (m/m) fine materials < 0.063 mm and the rest is sand fraction and fibers) was used to replace part of the virgin binder to be added to the RAP mixtures. The recycled roof membrane is processed, crushed and graded to sizes of 0-10 mm for surface course mixtures and 0-18 mm for base course mixtures. The GRM-50 was obtained from BituRec - a company in the Netherlands that processes the product. Extraction and recovery of the GRM-50 material was done using standard extraction and recovery procedure according NEN-EN 12697-1 and methylene dichloride was used as a solvent. Table 1 shows the properties of the binder recovered from the recycled materials (RAP and GRM-50) used in this research and Figure 1 shows the gradation of the recycled materials after extraction and recovery.

TABLE 1 Properties of the recovered binder in the recycled materials

Binder Properties (Recovered from recycled materials)	Unit	RAP from surface course mixture	RAP from base course mixture	GRM-50
Penetration @ 25°C	0.1 mm	25	29	19
Softening Point $T_{R\&B}$	°C	62	59	99
Binder content	% (m/m)	5.8	4.3	50

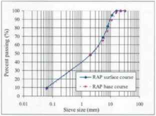


FIGURE 1 Gradation of recycled materials (after extraction and recovery).

Material preparation and specimen fabrication

In this research standard mixing method was used for the preparation of the asphalt mixes, for asphalt mixtures with RAP only the virgin aggregates and the RAP were heated to 170°C, on the other hand 180°C mixing temperature was used for asphalt mixtures containing RAP + GRM-50. The above mixing temperatures were set by determining the Equiviscous temperature, which refers to the temperature at which the binder attains a viscosity of 170cSt. Laboratory test specimens were prepared for different mechanical tests used in this study. The cylindrical specimens were compacted with a gyratory compactor, during the compaction 0.82 degree angle of compaction, 30 gyrations per minute, and 600 kPa compaction pressure was applied in the specimen. The target void contents for surface course mixtures were set to 4.5% and the base course mixtures were compacted to target air void content of 5%, Dutch specification (Standaard RAW Bepalingen 2010) prescribes a maximum amount of air void content of 2-6% and 2-7% for surface and base course mixtures respectively. The beams were compacted using a Shear PRES box compactor [3] and then sawn to the required dimensions. Table 2 presents the mean values of the air void contents. All the air void contents were ± 1% of the target values. For each mixture 4 cylindrical specimens were prepared for triaxial test. For stiffness and fatigue tests, at least 12 rectangular beams were used for surface and base course mixtures.

TABLE 2 Asphalt mixtures composition and volumetric

Mixture type	% RAP	% GRM-50	Binder content in mixture % (m/m)	Air void (%)	Bulk Density (kg/m^3)
AC 11 Surface course	30	0	5.6	4.1	2382
AC 16 Surface course				4.7	2394
AC 11 Surface course	30	3	5.6	3.9	2404
AC 16 Surface course				4.0	2405
AC 22 base course	50	0	4.3	4.9	2392
	50	3.2		4.3	2395

TABLE 3 Amount of new and old binder in the mixtures

Mixture type	Binder obtained from RAP % by mass (m/m)	Binder obtained from GRM-50 % by mass (m/m)	New binder Added % by mass (m/m)
AC 11 &16 30% RAP	1.74	-	3.86
AC 11 & 16 surface 30% rap + GRM-50	1.74	1.5	2.36
AC 22 Base 50% RAP	2.15	-	2.15
AC 22 Base 50% RAP + GRM-50	2.15	1.6	0.6

From Table 3 it can be seen that by using recycled roof membrane in asphalt mixtures considerable amount of new binder was saved, 1.5% by mass (m/m) and 1.6% by mass (m/m) of the new binder was substituted by bitumen obtained from GRM-50 for surface and base course mixes respectively.

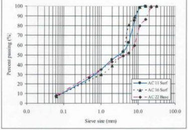


FIGURE 2 Final gradations of the asphalt mixtures (after extraction and recovery).

From Figure 2 it can be seen that the surface and base course asphalt mixtures are continuously graded with percentage of sand fraction (0.063 mm-2 mm) 39% and 43% for surface and base course mixtures respectively.

Testing plan

Binder tests

The testing plan includes both empirical and fundamental testing for binders. Empirical tests conducted on the virgin and recovered binders include the penetration and softening point tests. The penetration test was conducted according to the norm NEN-EN1426 at 25°C and the softening point according to NEN-EN 1427. The rheological properties of the binders were determined using Dynamic Shear Rheometer (DSR) equipment; frequency sweep tests were conducted to determine the complex modulus and the phase angles. In this research 8 mm parallel plate testing geometry with 2 mm sample thickness was used for the lower temperature range from -10, 0, 10 and 20°C and 25 mm parallel plate testing geometry with 1mm sample thickness was used for the higher temperature range of 30, 40, 50 and 60°C.

Asphalt mixture tests

The mixture performance tests were conducted according to the European procedures for type testing of asphalt mixtures and Standaard RAW Bepalingen 2010 (Dutch specification). The four point bending test was used to determine the mixture stiffness. The test was performed in accordance with NEN-EN 12697–26. Asphalt mixture specimens with dimension of 450 X 50 X 50 mm (L X W X H) were tested at test temperature 20°C and frequency sweep at 0.1, 0.2, 0.5, 1, 2, 5, 8, 10, 20 and 30 Hz. A strain level of 50 μ m/m was used for the determination of the stiffness in order to avoid damage of the specimens, because they were used for further fatigue tests. For each mixture in total 18 beams were prepared in order to determine the stiffness modulus.

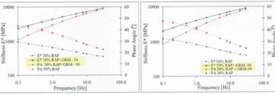
The four point beam bending test was used to characterise the fatigue properties of the asphalt mixtures. Tests were carried out according to NEN-EN 12697-24 annex E. Test specimens with dimension of 450 X 50 X 50 mm (L X W X H) were used. The tests were conducted at test temperature of 20°C and loading frequency of 30 Hz, which is a requirement frequency for fatigue testing according to European norm. During the testing three strain levels were selected (100, 120 and 150 μ m/m). For each strain level at least 4 beams were tested for a specific mixture.

The triaxial test was selected to determine resistance to permanent deformation of the mixtures. The test was conducted in accordance to NEN-EN 12697-25 test method B. For surface course mixtures cylindrical specimens 100 mm diameter and 60 mm height were used. The test temperature was 50°C and the specimens were conditioned at least for 4 hours before testing. During the test a constant horizontal confining stress of 0.15 MPa and a cyclic vertical amplitude of 0.3 MPa were applied (vertical stress between 0.15 and 0.75 MPa). The number of applied load cycles was 10000. For base course mixtures cylindrical specimens with 100 mm diameter and 80 mm height were used. The test temperature was 40°C and the specimens were conditioned at least for 4 hours before testing. During the test a constant horizontal confining stress of 0.05 MPa and cyclic vertical stress amplitude of 0.2 MPa were applied (vertical stress between 0.05 and 0.45 MPa), total load cycles were 10000.

TEST RESULTS AND DISCUSSIONS

Asphalt mixtures stiffness characteristics

The following section discusses the results obtained from the four point bending stiffness test, Figure 3 and 4 shows the stiffness results of the surface and base course mixtures at 20°C.



(a) AC 11 surface (b) AC 16 surf ace

FIGURE 3 Stiffness and phase angle at 20°C for the surface course mixtures

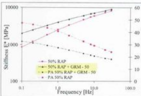


FIGURE 4 Stiffness and phase angle at 20°C for the base course mixtures.

From the above Figures it can be seen that mixtures with RAP and GRM-50 has higher stiffness values than the mixtures with only RAP. A higher stiffness increases the load-spreading ability of the asphalt layers and controls the level of traffic induced tensile strains in the bottom asphalt layer. In addition, mixtures with high stiffness values give higher resistance to permanent deformation at elevated temperatures. The results also show that mixtures with GRM-50 have a lower phase angle than mixtures with only RAP, which means that asphalt mixtures with recycled roof membrane have a higher storage modulus. This behaviour of the mixtures with GRM-50 is also reflected in the permanent deformation results which will be discussed in detail in the following sections.

Asphalt mixtures fatigue characteristics

Each point in Figure 5 and 6 is obtained from a strain controlled fatigue test whereby the number of load cycles at 50% of the initial stiffness is determined. In strain controlled fatigue test failure is defined as a 50% reduction in initial stiffness of the mixture. In Figure 5 and 6 are shown the fatigue test results of surface and base course mixtures with RAP and RAP + GRM-50. The relationship between strain levels and cycles to failure as plotted on a straight line were modelled using the following relationship.

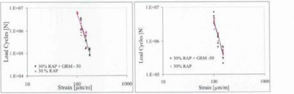
$$N_f = k_1 \left(\frac{1}{\varepsilon} \right)^{k_2} \quad (1)$$

Where N_f = number of cycles to failure

ε = flexural strain a

k_1 and k_2 = regression constants

The k_1 and k_2 coefficients were obtained from a best fit line of the data.



(a) AC 11 surface (b) AC 16 surf ace

FIGURE 5 Fatigue life of AC 11 surface course mixture

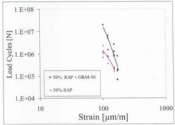


FIGURE 6 Fatigue life of AC 22 base course mixture

TABLE 4 Fatigue line regression coefficients

Mixture Type	logk1	k2	R2
AC 11 Surface 30% RAP	18.85	6.027	0.771
AC 16 Surface 30% RAP	17.251	5.327	0.924
AC 11 Surface 30% RAP + GRM-50	20.717	7.009	0.764
AC 16 Surface 30% RAP + GRM-50	18.767	6.043	0.866
AC 22 Base 50% RAP	17.461	5.626	0.704
AC 22 Base 50% RAP + GRM-50	23.646	8.135	0.773

From Figure 6 it can be seen that the GRM-50 has significantly improved the fatigue characteristics of the AC 22 base. The addition of GRM-50 improves for example the fatigue life of the mixture at strain level of 120 μ m/m by a factor of 6.8. For the surface mixtures this trend can not be shown. The reason could be related to the binder content, the composition of the binder and the percentage of recycled material in the mixture.

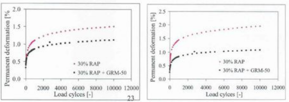
From the fatigue test results and the information given in Table 3 about the binder content and composition, some possible reasons are given for the difference in fatigue life of the base and surface mixtures, namely:

- The fact that the surface mixtures have higher binder content and at the same time a lower GRM-50 binder content, reduces the influence of the recycled roof membrane.
- From the composition of the binder in the mixtures, the higher the amount of new binder in the mixture implies a lower effect on the mixture fatigue performance.

The positive effect of the recycled roof membrane GRM-50 on fatigue life of base course mixtures is important characteristics, as it is known for flexible pavements fatigue cracking is a dominate pavement distress for bottom layers due to higher magnitude of flexural tensile strain due to traffic loading.

Permanent deformation of the asphalt mixtures

Figure 7 and 8 show permanent deformation results for the surface and base course mixtures.



(a) AC 11 surface course (b) AC 16 surface course

FIGURE 7 Permanent deformation versus number load cycles for the surface course mixtures

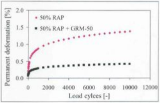
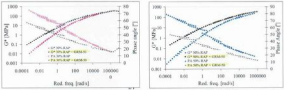


FIGURE 8 Permanent deformation versus number load cycles for the base course mixtures.

From the results it can be clearly seen that mixtures with GRM-50 give much lower permanent deformation than mixtures with RAP only. From Figure 7 (a) it can be seen that the total permanent deformation reduced by 50%, while in Figure 7 (b) the total permanent deformation resistance reduced by 100%, the same trend also observed for base course mixture in Figure 8. This can be explained by the fact that in both cases the virgin softer binder is replaced by APP modified binder. Mixtures with high resistance to permanent deformation are used on road sections with heavy traffic, slow moving heavy traffic, at crossing with stop lights and other locations.

Recovered binder properties

In Figure 9 the master curve of the complex shear modulus and phase angle of the binder recovered from asphalt mixtures containing normal RAP and RAP + GRM-50 are given. Using the Time-Temperature Superposition principle the master curves of the complex modulus and phase angle were constructed at a reference temperature of 20 °C.



(a) AC 16 surface course (b) AC 22 base course

FIGURE 9 Complex shear modulus and Phase Angle of recover binders at T_{ref} 20 °C (AC 16 Surface and AC 22 Base course).

As can be seen from Figure 9 (a), the recovered binder from AC 16 Surface course mixture with RAP + GRM-50 has a higher complex shear modulus than the recovered binder from the mixture with only RAP. Especially at lower frequencies (high temperature) a significant difference in the complex shear modulus can be observed up till a factor of 10. It can be seen from Figure 9 that the addition of GRM-50 improved the elastic response (lower phase angles) compared to the recovered binder containing RAP. The lower phase angle at the low frequency range (high temperature) implies a higher storage modulus component which is important for the permanent deformation resistance at high temperature. The same trend is also observed for the complex shear modulus and phase angle for AC 22 Base mixtures in a wide range of frequency range, see Figure 9 (b). The complex shear modulus of the recovered binder from AC 22 Base RAP + GRM-50 mixture is higher compared to the reference mixture with only RAP, especially at the low frequency range (high temperature). From the master curve results it can be seen that for surface course mixtures with RAP and RAP + GRM-50 the complex shear modulus at low temperature (high frequency) seems similar, whereas for AC 22 base course mixtures addition of GRM-50 slightly increases the complex shear modulus at low temperature (high frequency) range as compared to base course mixture containing RAP only, it is important to see in detail the effect of GRM-50 on mixture low temperature properties in the coming researches.

CONCLUSIONS

Based on the test results and the discussion presented above, the following conclusions can be made:

- Asphalt mixtures with RAP + GRM-50 show higher mixture stiffness and a lower phase angle which improves the mixture rutting resistance at the high temperature range.
- For base course asphalt mixtures addition of recycling roof membrane (GRM-50) significantly improved the fatigue performance, which in combination with the higher stiffness may allow considerable thickness reduction in pavement design.
- All mixtures with RAP + GRM-50 perform better in terms of permanent deformation resistance, which is beneficially in heavily loaded areas, with slow moving traffic and road crossings.
- From the master curve results of the recovered binders it can be illustrated that there is significant improvement in binder complex shear modulus especially at low frequency range (high temperature). However, it is unclear if these properties can be directly translated to the mixture because of the uncertainty over the blending.

REFERENCES

1. T. Kneepkens, H. Schaefer, M.kersten, *Dakleer lager aan de grond kansen voor het milieu* (in Dutch), The Dutch Asphalt Pavement Association (VBW) , asfalt number 1, pp. 22-23, 2006.
2. H. Schaefer, T. Kneepkens, J. Groenendijk, *BSA 100, het asphalt van de toekomst* (in Dutch), The Dutch Asphalt Pavement Association (VBW), asphalt number 4, pp. 22-25, 2009.
3. J. Qiu, D. Xuan, M.F.C. van de Ven, A.A.A. *Molenaar, Third International Conference on Advances and Trends in Engineering Materials and their Applications,* Montreal, Canada, 2009.

4. J.J. Foxlow, J.S. Daniel, A.K. Swamy, *RAP or RAS? The differences in Performance of HMA containing Reclaimed Asphalt Pavement and Reclaimed Asphalt Shingles*, Journal of the Association of Asphalt Paving Technologist, Vol 79, pp.347-376, 2010.
5. A.A. Cascione, R.R. Williams, W.G. Buttlar, S. Ahmed, B. Hillas, D.S. Haugen, S. Gillen, *Laboratory Evaluation of field Produced Hot Mix Asphalt Containing Post-Consumer Recycled Asphalt Shingles and Fractionated Recycled Asphalt Pavement* , Journal of the Association of Asphalt Paving Technologist, Vol 79, pp.377-418, 2010