The development of 100% RAP asphalt mixture with the use of innovative rejuvenator

Eyassu Hagos[1, a], Morteza Shirazi[2], Alex van de Wall[3, b]

[1] *KWS-InfraLinQ, Hoogblokland, Netherlands*
[2] *Latexfalt BV, Koudekerk aan den Rijn, Netherlands*
[3] *KWS-InfraLinQ, Vianen, Netherlands*

[a] ehagos@infralinq.com
[b] avandewall@infralinq.com

Digital Object Identifier (DOI): dx.doi.org/10.14311/EE.2016.093

ABSTRACT

The use of up to 50% Recycled Asphalt Pavement (RAP) in asphalt mixtures is a standard practice in the Netherlands. There is a high demand to increase the percentage of RAP in asphalt mixtures because of the economic and environmental benefits. Currently the maximum possible use of RAP without a rejuvenator is about 70%. One of the factors limiting the use of high percentages of RAP is the hardening of bitumen in the RAP because of aging. In this study the use of 100% RAP with the addition of a rejuvenator was successfully implemented. The rejuvenator was developed to restore the original characteristics of the bitumen and its effectiveness has improved the characteristics of 100% RAP mixture. Performance indicators such as stiffness en fatigue characteristics were researched. Comparable mixture performance with a reference asphalt mixture has been achieved. As a follow up of this research a test section of 100% RAP has been laid to verify the test results. The use of high percentage RAP seems promising not only in the underlying asphalt layers but also in top layers.

Keywords: Ageing, Performance testing, Reclaimed asphalt pavement (RAP) Recycling, Rejuvenators

1. INTRODUCTION

The use of a Reclaimed Asphalt Pavement (RAP) in asphalt mixtures has steadily increased in recent years. This is because of the enormous benefits, both economic and environmental, associated with high percentage use of RAP. It is highly encouraged in the Netherlands to use RAP in asphalt mixtures as it contributes to a sustainable use of road building materials and pavement durability. On the other hand. it is a huge challenge to sustain the quality of the asphalt beyond certain percentage of RAP in the mixture (usually 70%). As a result, additives are used to rejuvenate the bitumen characteristics in the RAP with the aim to improve the asphalt properties. Asphalt mixture with high RAP content is therefore possible with the use of an effective rejuvenator that restores the original characteristics of the bitumen [1, 2]. This paper discusses the performance of the 100% RAP mixture with the addition of an innovative rejuvenator from Latexfalt known as Modiseal RR. The research into the development of the rejuvenator is not discussed in this paper; but reference is provided [1].

Asphalt mixtures with high percentage of RAP are mainly used in the bottom-layers of an asphalt construction (base and/or binder courses). In the Netherlands, the reference Asphalt Concrete (AC) mixture for base-course is based on 50% RAP content. Higher percentage use of RAP can also be permitted as long as the asphalt properties comply with the functional requirements (performance criteria) in the specification. These performance requirements are based on the stiffness, fatigue, permanent deformation and water sensitivity characteristics of the asphalt mixture. It seems that the upper limit of RAP content to comply with the minimum performance requirements of an asphalt mixture is about 70%. Beyond this limit, a rejuvenator should be used to recover the lost properties of the binder in the RAP as a result of aging. For this reason, the use of an innovative rejuvenator becomes necessary which will broaden the limit even to 100% RAP mixture. To realise a 100% RAP mixture, InfraLinQ (KWS Infra) has conducted this research jointly with Latexfalt. Latexfalt has researched and developed the innovative rejuvenator while InfraLinQ carried out the asphalt mixture performance testing to evaluate the effectiveness of the rejuvenator. The Modiseal RR rejuvenator is based on plant ingredients, which is optimized to effectively diffuse in the bitumen, restore the chemical as well as mechanical properties of the bitumen. It is also effective in resisting excessive aging during production and laying of the asphalt mixture. These characteristics of the rejuvenator makes it ideal to use in the 100% RAP mixture which, as reported in this paper, resulted in comparable asphalt mixture properties as a reference mixture with 50% RAP.

2. MATERIALS AND TESTING METHODS

2.1 Materials and methods

The test program is based on determining the right quantity of rejuvenator needed to add in a 100% RAP mixture to produce equivalent characteristics or performance level as a reference mixture (AC 16 base with 50% RAP). Asphalt mixtures without a rejuvenator and with 4, 7 and 10% rejuvenator content by mass of the bitumen in the asphalt were investigated. The evaluation of the mixture characteristics is based on the mixture volumetric properties and a simple mixture performance criteria to determine the optimum rejuvenator content. The evaluation methods are based on:

- bitumen properties (empirical and fundamental),
- the Marshall test, and
- the Indirect Tensile Strength (ITS) test.

The mixture with the optimum rejuvenator content was further investigated to determine the fundamental mixture properties. These properties, i.e. the sensitivity to water damage, the resistance to permanent deformation, the stiffness and fatigue, were determined in the same way as in a typical typetest (TT). The testing plan is given in Table 1. A schematic diagram of the testing program is also shown in Figure 1.

Table 1: The testing program

Marshall tablets	RAP 100% with rejuvenator			
Rejuvenator (% m/m bitumen)	0%	4%	7%	10%
Bitumen characteristics (pen, R&B temp., Rheology G* & δ)	√	√	√	√
Mixture characteristics (density, voids, etc...)	√	√	√	√
Marshall test (Stability, Flow, Quotient)	√	√	√	√
Indirect tensile strength (ITS)	√	√	√	√
Water sensitivity (ITSR)	√		optimum rejuvenator content 3.3%	
Stiffness and Fatigue characteristics	√			
Resistance to permanent deformation	√			
Test-section of the mixture	√			

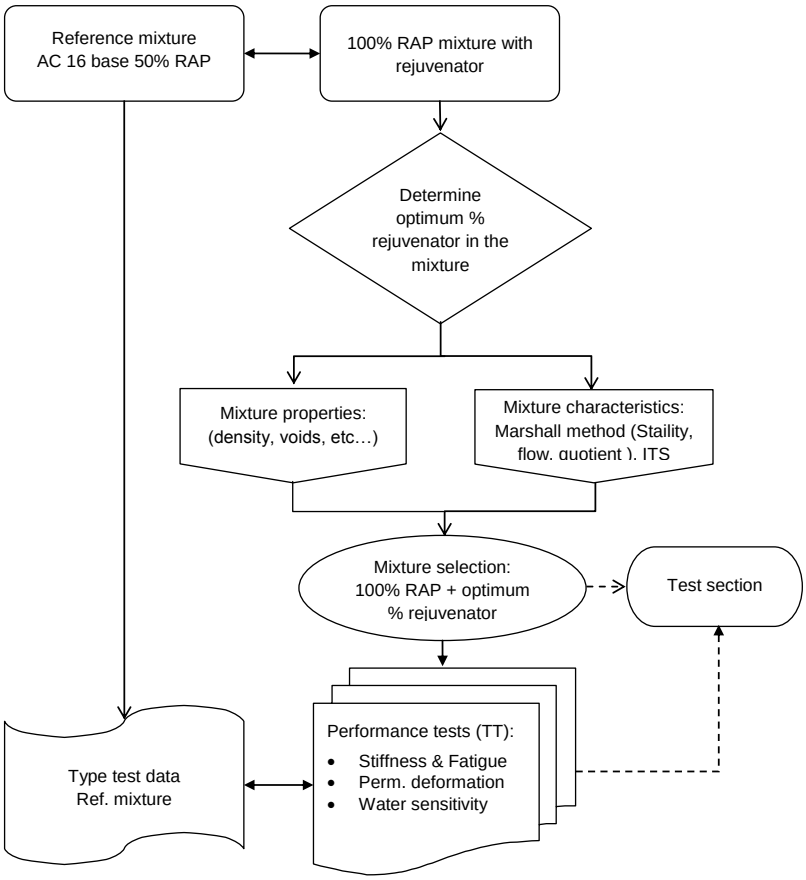

Figure 1: schematic diagram of the testing program

The RAP obtained from the milling of an existing pavement is first broken into smaller sizes using a crusher and is used "as is" to produce 100% RAP asphalt mixture. The target gradation of the AC 16 base 100% RAP is the same as the RAP gradation itself. The target gradation of the reference mixture and the gradation of the RAP used in the laboratory and the test section are given in Table 2. This same data is also shown graphically in Figure 2.

The mixture composition of the 100% RAP asphalt mixture is given in Table 3.

Table 2: Gradation of RAP and the reference asphalt mixture

Pass sieve	AC 16 base 100% RAP		AC 16 base 50% RAP
	RAP (Lab)	Test-section	Reference mixture
C 22.4	100	100	100
C 16	98.4	99.6	97
C 11.2	89.4	90.0	81
C 8	76.2	78.2	67
C 5.6	62.4	67.2	56
2 mm	42.4	51.4	43
500 µm	28.8	36.5	29
180 µm	17.0	16.8	13
125 µm	13.0	11.9	10
63 µm	9.7	9.0	6.6
Bitumengehalte (in)	**4.9**	**4.3**	**4.6**
Bitumen properties:			
Penetration (0.1 mm)	21	28	
Softening point $T_{R\&B}$ (°C)	61	59.6	
Penetration Index, PI (-)	-0.7	-0.3	

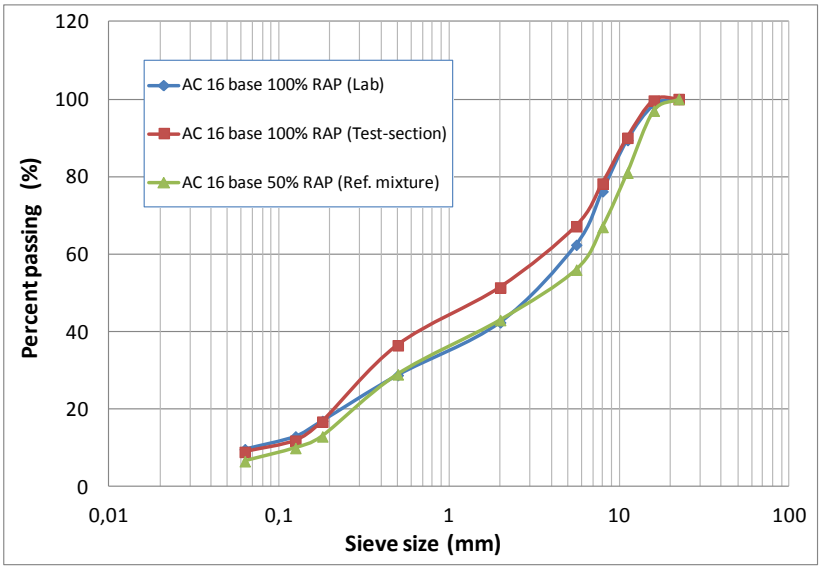

Figure 2: Gradation of the 100% RAP asphalt mixtures

Table 3: Asphalt mixture composition

Materials	Mixture composition (%) AC 16 base 100% PR
1. RAP	100
2. Bitumen 70/100	-
Total	100 % RAP
• Bitumen in RAP	4.9 %
• Rejuvenator	0.16 (3.3%)*
	* relative to RAP bitumen

3. RESULTS

3.1 Determining optimum rejuvenator content

From previously conducted Dynamic Shear Rheometer (DSR) test on the RAP bitumen, it is found out that 10% (m/m) rejuvenator will provide comparable rheological properties (complex modulus G* en fase angle δ) as a 70/100 penetration bitumen [1]. Since the reference bitumen consists of 50% RAP and a 70/100 pen new bitumen, a combined property of the blended bitumen will be a 40/60 pen. The rejuvenator needed to achieve similar bitumen properties as in the reference mixture will be 5% (m/m). Similar studies are based on correlating the microstructure of the bitumen with its rheological properties [3] or Superpave performance grade specifications [4] to determine the compatibility and optimum content of the rejuvenator in the RAP bitumen.

Empirical test results on the recovered bitumen from a mixture of 100% RAP with various percentages of rejuvenator is shown in Figure 3. Accordingly, the average rejuvenator content which is needed to achieve the same properties (penetration and softening point) as that of the reference bitumen is found to be 1.8%.

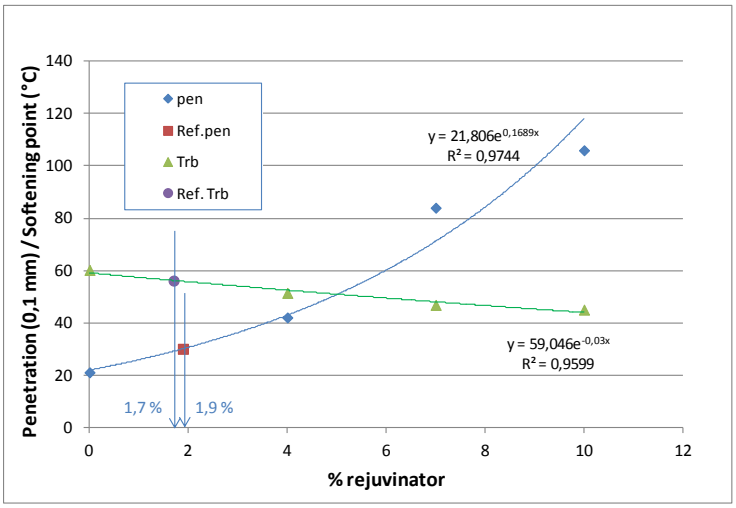

Figure 3: Penetration and Softening point results of 100% RAP mixtures with rejuvenator

The optimum rejuvenator content is determined based on a number of inputs, among which the density and voids of the mixture is one. Based on this simple volumetric property of the mixture, the optimum rejuvenator content that corresponds to the 3% voids in the reference mixture is found to be 1.9%.

The measured maximum and bulk densities and the voids content of the researched asphalt mixtures are given in Table 4 and Figure 4. In Figure 4 the amount of rejuvenator to achieve the air voids of the reference mixture is indicated.

Table 4: Measured densities and air voids of asphalt mixtures

Asphalt mixture	Rejuvenator* %	Max. density kg/m^3	Bulk density kg/m^3	Voids %
100% PR without rejuv.	0	2426	2353	3.9
100% PR + 4% rejuvenator	4	2438	2384	2.2
100% PR + 7% rejuvenator	7	2422	2382	1.7
100% PR + 10% rejuv.	10	2429	2399	1,2
Reference mixture (AC 16 base 50% PR)		2470	2396	3.0
Test section: AC 16 base (100% PR)		2468	2330	5.6

** Rejuvenator % relative to bitumen content in RAP*

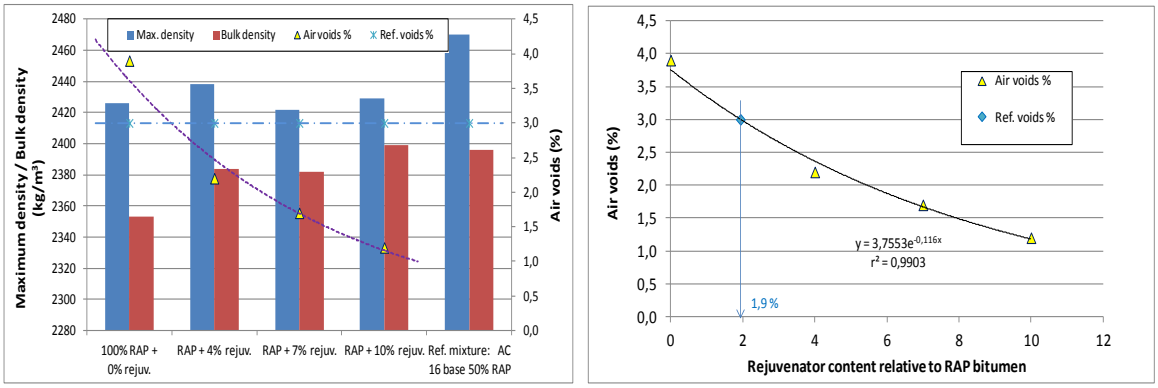

Figure 4: Density and air voids - 100% RAP mixtures with rejuvenator

Based on Marshall test, the stability and quotient of the asphalt mixture are compared with the reference mixture. The test results of the Marshall test are shown in Figure 5. The rejuvenator content needed to achieve the stability and quotient corresponding to the reference mixture are indicated in Figure 5. Accordingly, the rejuvenator that will provide the same stability and quotient as that of the reference mixture are determined to be 5.4% and 2.2% respectively.

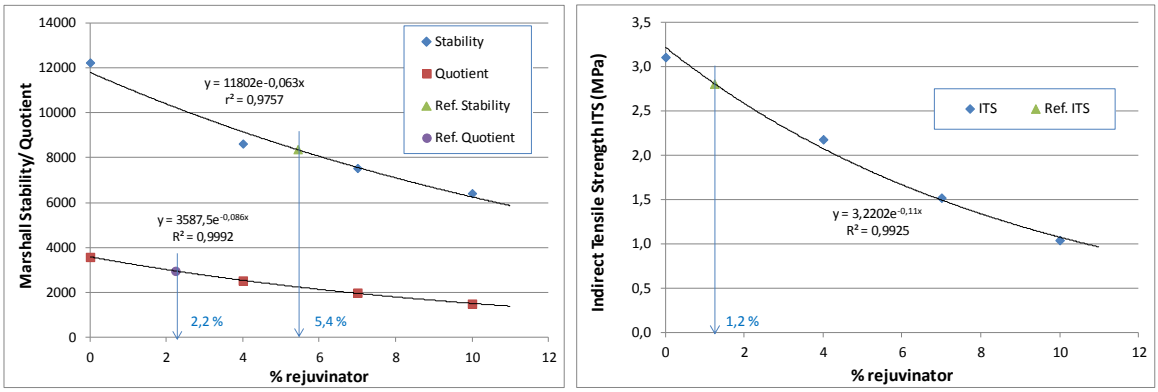

Figure 5: Marshall and ITS test results of the 100% RAP mixtures and the reference mixture

Last but not least, the Indirect Tensile Strength Test (ITT / ITS) on cylindrical specimens was also used to determine the optimum rejuvenator content. In Figure 5 is the results of the ITS shown with the ITS of the reference mixture. The rejuvenator content that corresponds to the reference mixture's ITS is shown in Figure 5. Based on the ITS performance indicator, the rejuvenator content needed to add in the 100% RAP mixture is determined to be 1.2%.

The overall optimum rejuvenator content is determined taking into account the weighted average of all the rejuvenator contents corresponding to the various performance indicators. In Table 5, an optimum rejuvenator content of 3.3% is determined based on a weighted average method. The weight contributions of the bitumen characteristics and mixture performance is made to be equal. The functional bitumen property, i.e. the DSR rheological characteristics G* and δ, is given more weight for two main reasons. First, rheology provides fundamental properties over a wide range of temperatures in comparison with empirical properties. Second, because of the fact that bitumen important role plays in determining the mixture property; all other factors remaining the same in the mixture.

Table 5: Weighted average method to determine the optimum rejuvenator content

Bitumen / Asphalt Mixture property	Weight (-) (a)	Rejuvenator content (%) (b)	Weighted average (%) (c) = (a) * (b)
Bitumen properties			
Pen en T_{RB}	0.10	1.8	0.2
DSR: G* en δ	0.40	5.0	2.0
Mixture volumetric properties			
Air voids	0.15	1.9	0.3
Mixture performance indicators			
Marshall: Stability & Quotient	0.15	3.8	0.6
Indirect Tensile Strength ITS	0.20	1.2	0.2
Total	1.00		**3.3 %**

3.2 Performance test on the selected mixture

The 100% RAP mixture with the weighted-average optimum rejuvenator content of 3.3% was further researched. This was necessary in order to determine the effectiveness of the rejuvenator in recovering the original binder characteristics in the RAP. The additional investigation is based on the determination of the fundamental mixture properties, such as the stiffness & phase angle, the fatigue characteristics, the permanent deformation and water sensitivity properties. These tests are standard type test carried-out to attach a CE certificate to a dense asphalt mixture.

Accordingly, a full type test has been conducted to determine the performance of the 100% RAP mixture.

Stiffness and fatigue tests
The stiffness and fatigue tests are conducted in the same manner as in a standard type test in a 4-point bending beam (4PB) test setup. The test conditions for the 4PB stiffness and fatigue tests are given in Table 6. The results of the stiffness test are shown in Table 7 both for the reference and the 100% RAP mixtures.

Table 6: Test conditions 4-point-bending (4PB) test

Test conditions	Stiffness	Fatigue
Specimen dimension	50 x 50 x 420 mm	50 x 50 x 420 mm
Temperature	20°C	20°C
Strain (μm/m)	50 (18 beams)	3 levels (3 x 6 beams)
Frequency (Hz)	0.1 to 30 Hz	30 Hz

Table 7: Stiffness and Phase angle test results

Frequency (Hz)	Reference mixture: AC 16 base 50% RAP		RAP mixture: 100% RAP + 3.3% rejuvenator	
	Stiffness (MPa)	Phase angle (°)	Stiffness (MPa)	Phase angle (°)
0.1	2,318	39.9	1,909	40.8
0.2	3,000	37.6	2,462	39.1
0.5	4,143	34.0	3,439	36.6
1	5,169	31.0	4,367	34.5
2	6,340	27.8	5,420	32.1
5	8,054	23.9	7,007	28.7
8	**8,978**	**22.0**	**7,979**	**26.1**
10	9,411	21.2	8,405	24.2
20	10,780	18.9	9,902	23.7
30	11,469	17.8	10,889	22.5

The fatigue line can be described by the following equation:

$$\ln(N_f) = A_0 + A_1 \cdot \ln(\varepsilon_i)$$

Whereby:
N_f = Load cycles to failure
ε_i = Strain (ε_6 = strain level that corresponds to 1 million load cycles)

The parameters of the fatigue line are given in Table 8.

Table 8: Fatigue coefficients (parameters)

	Reference mixture AC 16 base 50% RAP	RAP mixture 100% RAP + 3.3% rejuvenator
A0	37,083	40,906
A1 (slope)	-4,982	-5,446
ε_6 (μm/m)	**107**	**145**

Permanent deformation

The resistance to permanent deformation is determined with the cyclic triaxial test. The test conditions of thet triaxial test are given in Table 9.

Table 9: Test conditions of the triaxial test

Test conditions	
No. of specimens	6
Loading signal	Haversine
	- loading time 0.6 s
	- rest period 0.4 s
Temperature	40°C
Vertical stress, σ_v	50 KPa
Confining pressure/stress, σ_c	0.20 MPa

An example of the triaxial test result is shown in Figure 6. The fitting to the steady state deformation (from 4000 to 10000 loading cycles) can be represented by the following equation:

$$\varepsilon_n = A1 + B1 * N \quad (N > 4{,}000)$$
$$f_c = B1 \times 10^4$$

Whereby:
ε_n = permanent deformation
N = loading cycle
A1, B1 = fit parameters
f_c = slope of the fit-line per 1000 cycles

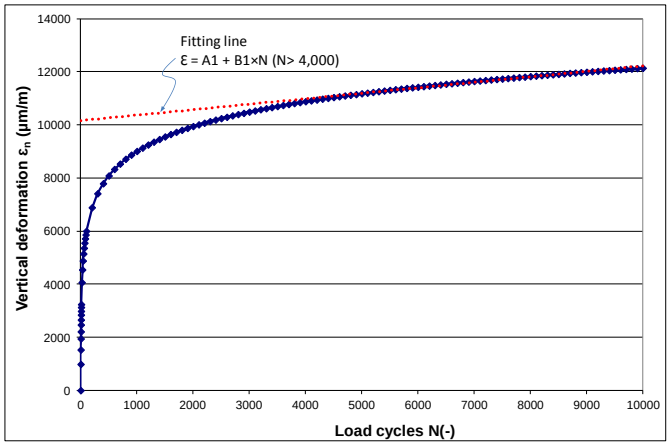

Figure 6: Test result of a triaxial test

The average values of the parameters of the line fitting to the results of the triaxial test is given in Table 10 together with that of the reference mixture. Comparison of the test results shows that both asphalt mixtures have fc value under the 0.2, which implies that both mixtures can be used in road construction of all traffic classes including heavy duty.

Table 10: Parameters of the fitting line to permanent deformation

Parameter	Reference mixture	RAP mixture
	AC 16 base 50% RAP	100% RAP + 3.3% rejuvenator
A1	0.5659	0.8282
B1	1.52E-05	1.58E-05
f_c	0.15	0.16

Sensitivity to water damage

The sensitivity to water damage is the ratio of the wet (specimens conditioned in water for 72 hours) to dry (not conditioned) Indirect Tensile Strength (ITS) determined at 15°C. The 100% RAP mixture has an ITS ratio (ITSR) of 93% and that of the reference mixture is 89.6%. Basically both mixtures satisfy the minimum requirement of 80% for application as a base mixture.

4. ANALYSIS

All test results indicate that the performance of the 100% RAP mixture is the slightly better compared to the reference mixture. This implies that the use of the 100% RAP mixture in asphalt construction will not only have an advantage in terms of cost saving but also performance.

With regard to stiffness and fatigue properties, the 100% RAP mixture seems to be a better mixture than the reference mixture (refer to Figure 7). Although the mixture has a stiffness of 7979 MPa (8 Hz), which is about 1000 MPa less than the reference mixture, its fatigue property (ε_6 = 145 μm/m) makes it a superior mixture in comparison with the reference mixture (ε_6 = 107 μm/m). Fatigue is a governing design criteria for a base asphalt layer, because of this the 100% RAP mixture will likely have the advantage of having a thinner asphalt thickness to provide the same design life as the reference mixture. This is a double advantage in cost saving because the 100% RAP is already a cheaper mixture than the reference mixture.

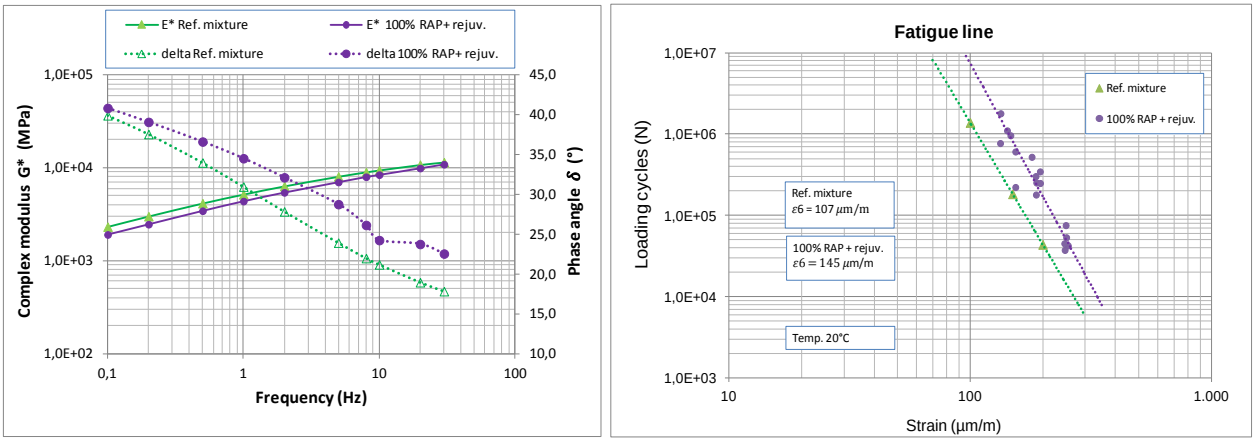

Figure 7: Stiffness and fatigue properties of a Ref. and a 100% RAP + rejuv. mixtures

With regard to the resistance to permanent deformation and resistance to water damage, the 100% RAP mixture has comparable properties as the reference mixture. Both mixtures fulfil the minimum requirements for a base and binder layers in accordance to the RAW specification [5].

Because of the outstanding results that the 100% RAP mixture with a rejuvenator has showed, i.e. equivalent or better performance compared with a reference mixture, it was necessary to evaluate the performance of the mixture in the field. For this reason, a test section has been laid in the vicinity where the pavement is trafficked with slow moving heavy loaded trucks. The production of the mixture was conducted with an innovative idea where the RAP is heated indirectly with hot-air called the HERA-system. It is known that innovative production process contributes towards improved performance [6]. The evaluation of the test section will provide extra guaranty to apply the mixture in a larger scale. It is promising that the pavement is performing very well after 1 year of service.

It should be noted that a good processing of the RAP to attain a consistent quality is a necessary thing. Fractioning the RAP into 3 or more different sizes is an important step to get a full control over the gradation of the 100% RAP to produce better quality asphalt.

5. CONCLUSION

The following conclusions are drawn from the research conducted on the mixture 100% RAP with rejuvenator.

- 100% RAP mixture can be realised with an addition of an innovative rejuvenator.
- The addition of optimum rejuvenator content (3.3% by mass) ensured equivalent or even slightly better performance of the 100% RAP mixture compared with a reference mixture (AC 16 base with 50% RAP). The mixture has better fatigue characteristics and all other properties such as resistance to permanent deformation and water damage are comparable with the reference mixture.
- The 100% RAP mixture has multiple advantages: it is a cheaper alternative to the reference mixture because of the recycling, it may reduce the thickness of the asphalt layer because of its comparatively improved fatigue characteristics, and it is an environmentally friendly product in the sense that the contribution of recycling/re-use positive is in reducing environmental impacts.
- The 100% RAP mixture has the advantage to be used as a base and binder layer in the pavement construction. In addition, the 100% RAP mixture can be applied in pavements of all traffic classes including heavy duty.

6. REFERENCE

[1] Reintroducing the Intrinsic Self-healing Properties in Reclaimed Asphalt. J. Qui et al., Internal report: IOP SHM 012019, TU Delft., 2013.

[2] 100% recycling asphalt, T. Eijkenboom, Bouwend Nederland asfalt blad, March 2013.

[3] Turning Back Time: Rheological and microstructural assessment of rejuvenated bitumen, S.N. Nahar et al., TRB 93rd Annual Meeting Transportation Research Board, Washington, USA, 12-16 January 2014.

[4] Determining optimum rejuvenator dose for asphalt recycling based on Superpave performance grade specifications. M Zaumanis et al, Construction and building materials journal 69, pp 159-166, 2014.

[5] Standaard RAW bepalingen 2010, CROW kennisplatform voor infrastructuur, verkeer, vervoer en openbaar ruimte, pp. 621-622, 2010.

[6] 100% recycled hot mix asphalt: a review and analysis, M Zaumanis et al, Resource, conversation and Recyling journal 92, pp 230-245, 2014.