INFLUENCE OF THE QUALITY OF RECLAIMED ASPHALT ON THE FUNCTIONAL PROPERTIES OF THE NEW ASPHALT MIX

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ABSTRACT

In the Netherlands most of the reclaimed asphalt (RAP) is reused in new asphalt mixtures. In binder and base layers, up to 60% RAP is reused. In practice, various qualities of RAP are available, e.g. more or less bitumen, crushed or round large aggregates and natural of crushed sand. It is expected that the quality of the new mix will strongly depend on the properties of the RAP. For this reason, there are limitations mentioned in the European product standards with respect to the use of RAP. In the Netherlands there is also a restriction with respect to the shape of the aggregates in the RAP: if the reclaimed asphalt is used in surface or binder layers, than the coarse graded aggregate parts should comply to C90/1 according to EN 13043.

To determine the influence of the shape of the coarse aggregates in RAP, an extensive research program has been carried out using 3 qualities of RAP: one containing only crushed coarse aggregate parts, one containing only round coarse aggregates (gravel) and a 50/50% mix of both qualities. With these qualities, new asphalt concrete is produced using 60% of RAP. Various functional properties of the mixtures are determined: water sensitivity, stiffness and resistance to fatigue, to permanent deformation and to crack growth. Based on the results, it is concluded that only the resistance to permanent deformation is significantly affected by the quality of the RAP.

In this paper the research program is discussed and the findings are presented.

Keywords: Functional specifications, mechanical properties, reclaimed asphalt, recycling

1. INTRODUCTION

In the Netherlands, the warm re-use of reclaimed asphalt is common practice. In mixtures for base and binder layers, up to 60 percent by mass of reclaimed asphalt is put in the mix; in surface layers up to 30% by mass reclaimed asphalt is used. In order to accomplish these high amounts of re-use, in the Dutch regulations requirements are made with respect to the percentage crushed and round surfaces of the coarse aggregates in the reclaimed asphalt: for the re-use of reclaimed asphalt in surface and heavy loaded binder layers at least 90% of the coarse aggregate parts shall be totally crushed and only 1% can be totally round (=$C_{90/1}$). In practice this implies that reclaimed asphalt from gravel asphalt pavements can not be used as reclaimed asphalt for surface and binder layers. In times of shortage of reclaimed asphalt, this demand can lead to economical and environmental problems.

With respect to corporate social responsibility (CSR), BAM Roads tries to re-use secondary materials in such a way that the capital gains are as high as possible. Concerning the reclaimed asphalt from gravel asphalt, this implies that it is desirable that the demand for the $C_{90/1}$-value for binder layers could be disposed. For surface layers the $C_{90/1}$-requirement still holds in order to prevent skid resistance problems.

To determine the influence of the quality of the reclaimed asphalt on the functional properties of the asphalt mixtures, BAM Roads has performed an extensive research program on this topic. In this paper this research program is described and the results of this research are presented. First the research program will be discussed. Then the involved asphalt mixtures are presented. After discussing the test results, the conclusions and recommendations will be presented.

2. RESEARCH PLAN

It is not clear what the influence is of the use of a low quality reclaimed asphalt (LQRA; e.g. a reclaimed asphalt with a $C_{50/10}$ of $C_{50/30}$-value for the coarse aggregates) on the functional properties of the final mixture, compared to the use of a high quality of reclaimed asphalt (HQRA; e.g. a reclaimed asphalt with a $C_{90/1}$, $C_{95/1}$ of $C_{100/0}$-value). Some research has been carried out in the past [1]. It was concluded then that the quality of the reclaimed asphalt has no negative influence on the functional properties of the final mix. Within the scope of CSR, BAM Roads wants to verify these findings.
The influence of the quality of the reclaimed asphalt on the functional properties of the final mix is determined by performing a complete functional type test on 3 different kinds of mixtures:

1. A mixture with 60 percent by mass of a HQRA;
2. A mixture with 60 percent by mass of a LQRA;
3. A mixture with 30 percent by mass of a HQRA and 30 percent by mass of a LQRA. In total again 60 percent of reclaimed asphalt is used in the mixture.

Although only a very small variety of properties of the reclaimed is investigated in the research program, an important parameter is taken into account: the original mix properties of the reclaimed asphalt and the shape of the coarse graded aggregates in the reclaimed asphalt. In practice this parameter can hardly be influenced during the intake procedure of reclaimed asphalt at the asphalt plant.

In these type tests the following properties are determined:

1. Water sensitivity according to EN 12697-12 and -23, using 15ºC as test temperature for the determination of the indirect tensile strength. The specimens have a diameter of 100 mm and a thickness of 50 mm;
2. Stiffness, according to Annex B of EN 12697-26. In this test the four point bending (4PB) device is used, where 18 beams (dimensions 450*50*50 mm) are tested at 20ºC to determine the stiffness properties of the mixture;
3. Resistance to fatigue, according to Annex D of EN 12697-24. Again the 4PB test is used. In this deformation controlled test, the fatigue properties of 18 beams are determined at 20ºC and 30 Hz;
4. Resistance to permanent deformation, according to Annex B of EN 12697-25. These triaxial tests are carried out at 40ºC, using a static confining pressure of 0,05 MPa and a dynamic vertical haversine stress signal between 0,05 and 0,45 MPa. The load pulse takes 0,4 s and the rest pulse 0,6 s. In total 10.000 load cycles are applied. The specimens have a diameter of 100 mm and a thickness of 60 mm;
5. Resistance to cracking, according to EN 12697-44. In this semi circular bending (SCB) test, specimens are tested at 0 and 20ºC. At mid length of the specimen, a notch is taking care of the start of the cracking process within the specimen.

3. INVOLVED MIXTURES

As a reference mixture, a AC 16 bin/base 20/30 is used. In this mix 60 %m/m of high quality reclaimed asphalt is used. The code of this mixture is 100/0. In a second mix 30 %m/m HQRA is used and 30 %m/m LQRA. This implies that 50 %m/m of the reclaimed asphalt in this mix is a HQRA and 50%m/m is a LQRA. The code of this mixture is 50/50. In the second mix only the LQRA is used; in total 60 %m/m is put in the mixture. The mix code is 0/100. It is noted that the angularity of the HQRA is $C_{90/1}$, whereas for the LQRA this value is $C_{50/30}$. The final mix composition is given in Table 1.

Table 1: The mix composition of the 3 mixtures in this research.

Mix components	Mixture code (HQRA/LQRA)		
	100/0	50/50	0/100
Crushed aggregates 8/16	19,4	14,2	8,8
Crushed aggregates 8/11	1,1	7,3	13,5
Crushed aggregates 4/8	0,1	3,2	6,2
Sand 0/2	17,1	13,1	9,0
Filler	0,3	0,4	0,6
Baghouse fines	0,2	0,2	0,2
HQRA 0/20	61,1	30,5	0
LQRA 0/20	0	30,0	60,1
Bitumen 70/100	0,7	1,1	1,6
Totaal	100,0	100,0	100,0

The target density, which is defined as the density of the mix after compaction in practice, of all three mixtures is 2370 kg/m^3. Information on the characteristics of the new bitumen, the bitumen from the reclaimed asphalt and of the final mixed bitumen are gathered in Table 2.

Table 2: Properties bitumen in the mixtures

Property	Unit	Mixture code (HQRA/LQRA)		
		100/0	50/50	0/100
Penetration bitumen 70/100	[dmm]	90		
Penetration bitumen HQRA	[dmm]	22		
Penetration bitumen in LQRA	[dmm]	13		
Mix penetration	[dmm]	27	27	27
Amount of bitumen	[%m/m]	4,3		
Ratio new:old bitumen	[-]	0,7 : 3,6 = 1 : 5,1	1,1 : 3,2 = 1 : 2,9	1,6 : 2,7 = 1 : 1,7

The fact that the mix penetration of all three mixes are identical is a coincidence. But it is a very lucky coincidence, because now it can be assumed that the binder properties of the mix, especially the stiffness of the binder, has only a minor influence on the mechanical properties of the mix. So the differences in test results, presented in this paper, are mainly caused by the characteristics of the coarse round and crushed aggregate parts in the mix.

4. TEST RESULTS

In this paragraph the results of the tests are presented and discussed.

4.1 Water sensitivity

The results of the determination of the water sensitivity are summarized in Table 3. Between brackets the type of failure is indicated.

Table 3: Results determination water sensitivity mixtures

Indirect Tensile Strength ITS	Unit	Mixture code (HQRA/LQRA)		
		100/0	50/50	0/100
Mean ITS after retainen	[MPa]	2,629 (C)	2,747 (C)	2,989 (A)
Mean ITS without retainen	[MPa]	3,723 (C)	3,670 (A)	3,539(A)
ITSR	[%]	71	75	81
European ITSR-class	[-]	$ITSR_{70}$	$ITSR_{70}$	$ITSR_{80}$

Based on these results the following conclusions can be drawn:

- With an increase of the amount of LQRA the ITS-value of the retained specimens increases;
- For the non retained specimens the ITS-value decreases as the amount of LQRA increases;

- Finally an increase in ITSR-value is found with an increasing amount of LQRA in the mixture. The mixture 0/100 shows the best performance with respect to water sensitivity.;
- The failure mode changes with the quality of the reclaimed asphalt: it changes from C to A when the amount of LQRA in the mix increases;
- Also the crack plane changes: using more LQRA (50/50 or 0/100), the more the mix collapses close to the adhesive zone between mortar and aggregates surface. In case just HQRA is used (code 100/0), the crack runs completely through the mortar.

Overviewing all results it can be concluded that the quality of the reclaimed asphalt hardly influences the water sensitivity of the asphalt mixture. The ITSR-value increases slightly when using more LQRA in the mix, but also the strength of the mix decreases.

4.2 Stiffness

In figure 1 the mean results from the stiffness tests are presented. In this graph, the mix stiffness S_{mix} and phase angle φ are given for the three mixtures at 20ºC and various frequencies. From these results it is concluded that the quality of the reclaimed asphalt in the mix does not influence the measured stiffness and phase angle. It is striking that the 100/0 mix (with only HQRA) shows the lowest stiffness value. Maybe this can be explained by the fact that in the 100/0 mix, the ratio between new and old bitumen is the lowest for all mixtures.

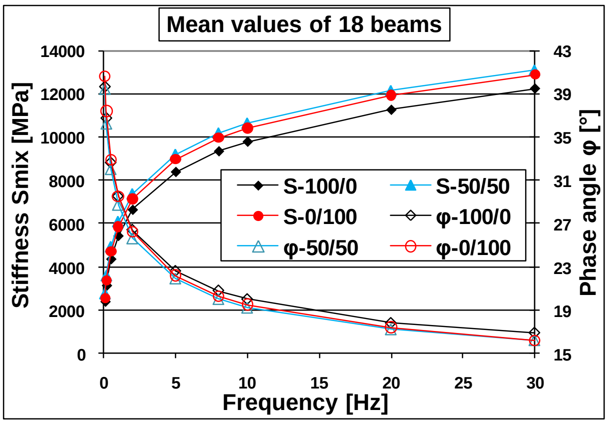

Figure 1: The measured stiffnesses and phase angles of the 3 mixtures

4.2 Resistance to fatigue

The resistance to fatigue is described with the following equation:

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

where:

N_f = the life span of a specimen [-];
ε = the applied strain in the displacement controlled test [µm/m];
k_1 and k_2 = regression coefficients.

Based on the test results on 18 beams, the strain ε_6 can be calculated where the fatigue life of 10^6 load repetitions is found. In Table 4 and Figure 2 the results of the fatigue tests are presented.

Table 4: Results fatigue tests at 20°C and 30 Hz

Parameter	Mixture code (HQRA/LQRA)		
	100/0	50/50	0/100
log (k_1)	18,42	16,92	16,95
k_2	6,19	5,43	5,38
ε_6 [in µm/m]	101,8	102,6	108,1
R^2	0,93	0,91	0,87

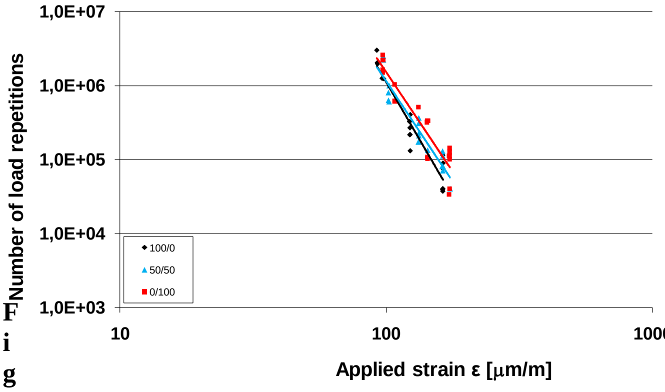

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Figure 2: Results of the fatigue tests

Based on these results, it can be concluded that the variation in fatigue lives decreases with an increase of HQRA in the mix. It also shows that the brittleness of the mix, which is correlated to the k_2-value, depends on the ratio between new and old bitumen in the mix. Based on the ε_6-value, hardly no differences occur between the 3 mixtures: for this reason all 3 mixtures comply with the same European fatigue class (100 µm/m < $\varepsilon_6 \leq$ 115 µm/m).

4.3 Resistance to permanent deformation

The resistance to permanent deformation is determined at 40ºC at loading conditions for binder and base layers. The length of the test is 10.000 seconds in which 10.000 load repetitions are applied. Fot each mix 4 specimens have been tested. In Table 5 and Figure 3 the average results of the tests are given. In this table the following parameters are used:

A, B = the intercept and slope of the permanent deformation line between 4.000 and 10.000 load repetitions;
ε_{max} = the maximum deformation [%];
f_{cmax} = 10.000*B.

Table 5: Results triaxial test at 40ºC

Parameter	Unit	Mixture code (HQRA/LQRA)		
		100/0	50/50	0/100
A	[-]	0,79	0,91	1,01
B	[µm/m/N]	$2{,}03\cdot10^{-5}$	$1{,}97\cdot10^{-5}$	$2{,}64\cdot10^{-5}$
ε_{max}	[%]	0,99	1,10	1,26
f_{cmax}	[µm/m/N]	0,20	0,20	0,26

Based on these results it can be concluded that the lowest resistance to permanent deformation (so the highest f_{cmax}-value) is found for the mix with only the LQRA (mixture code 0/100). The resistance to permanent deformation of the mixtures 100/0 and 50/50 are equivalent. Again a correlation is found between the ratio of old and new bitumen in the mix and the resistance to permanent deformation.

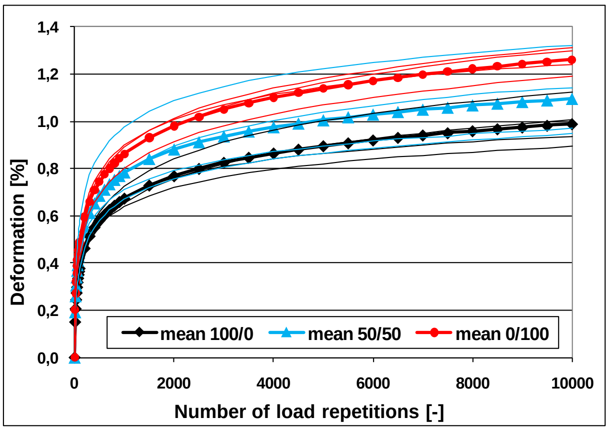

Figure 3: Results of the triaxial test to determine the resistance to permanent deformation

4.4 Resistance to crack growth

The resistance to crack growth is determined using the SCB-test (Semi Circular Bending test; see Figure 4). In this test a half circular specimen, provided with an notch halfway the right base of the specimen, is put on two rollers and loaded with a piston which moves with a constant deformation speed. This test is performed according to EN 12697-44 at a temperature of 0ºC, but the test is also performed at 20ºC. During the test de force and the position of the piston is recorded as a function of time. Based on the maximum force F_{max} which occurs at a deformation V_{max}, the maximum stress at failure can be calculated according to the following equation:

$$\sigma_{max} = \frac{4{,}263\,F_{max}}{D\,t} \qquad (2)$$

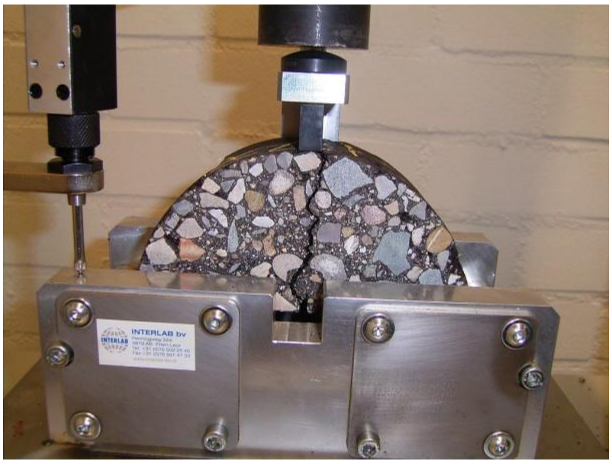

Figure 4: The SCB-test in progress

where D is the diameter and t the thickness of the specimen is.

In Figure 5A and 5B the results of the test are given. In the figures both the individual test results (6 specimens per mixture per temperature) as well as the average values are presented.

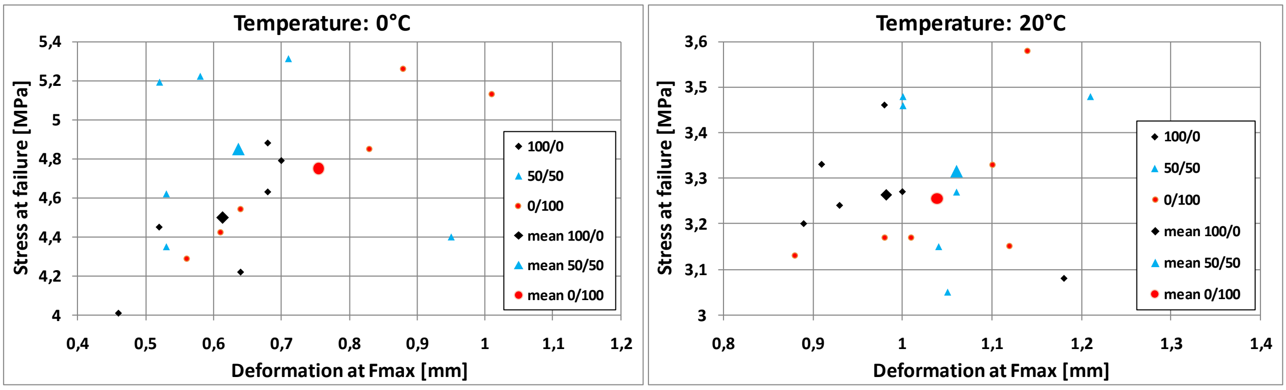

Figure 5A and 5B: Results crack resistance measurements at 0 and 20ºC

Based on these results it is concluded that at 0ºC the variation in test results is greater than at 20ºC. It is also fount that the variation in results increases with the percentage LQRA in the mix. However, there is no relation between the quality of the reclaimed asphalt and the parameter σ_{max} for the resistance to crack growth. This implies that the quality of the reclaimed asphalt hardly influences the crack growth resistance of the mixtures.

5. CONCLUSIONS AND RECOMMENDATIONS

Based on the results of this research project (in which only a small variety of properties of the reclaimed asphalt is applied), the following conclusions and recommendations can be formulated:

1. The quality of the coarse graded aggregate parts in the reclaimed asphalt hardy influences the mechanical properties of the resulting asphalt mixture. Only the resistance to permanence decreases when a low quality reclaimed asphalt with round aggregate parts is used;
2. There seems to be a relationship between the mechanical properties of the asphalt mixture and the ratio between the old bitumen from the reclaimed asphalt and the new dosed bitumen;
3. The influence of the binder stiffness on the mechanical properties of the various mixes was not a subject in this research program. This because in all three mixes the penetration of the bitumen in all three mixes ware identical. In practice the variety of binders and binder stiffnesses in the reclaimed asphalt shall have a major influence on the mix behaviour;
4. In the Netherlands, the requirement with respect to the quality of the reclaimed asphalt for binders can be become less strict in the regulations [2]. It is advised to drop the $C_{90/1}$-requirement for reclaimed asphalt in new asphalt mixtures for binders, except for the following situations:
   - for binders which will be used in practice as temporary surface layers because in this case skid resistance problems can occur;
   - on heavy trafficked pavements to prevent permanent deformation

REFERENCES

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