DESIGN AND PERFORMANCE OF HOT MIX ASPHALTS WITH HIGH PERCENTAGES OF RECLAIMED ASPHALT: APPROACH FOLLOWED IN THE PARAMIX PROJECT

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ABSTRACT

The use of reclaimed asphalt pavement (RA) in new asphalt pavements can provide important economical savings, while reducing the negative environmental impact. The European research project PARAMIX aims to improve the techniques for hot mix recycling in plant and cold mix in situ recycling, so as to increase the amount of reclaimed asphalt and develop competitive road pavement rehabilitation techniques.

This paper deals with the design of hot mix asphalts for the project. The different phases in the design process are described: the characterization of the reclaimed asphalt and the new material components, the volumetric mix design procedure and the laboratory study. Two types of mixes were considered: stone mastic asphalt and asphalt concrete. The percentages of reclaimed asphalt in these mixes were high: up to 30 % for the SMA and 50% for the asphalt concrete. The results of the performance tests show the feasibility to design and optimize good quality hot mix asphalts with a high percentage of reclaimed asphalt. The asphalt mixes have been applied on an experimental road.

Keywords: Mix design, reclaimed asphalt pavement, performance testing

1. INTRODUCTION

The “PARAMIX” project (“Road Pavement Rehabilitation Techniques Using Enhanced Asphalt Mixes”) is a research project supported by the European Commission in the frame of the “Competitive and Sustainable Growth” program. Eleven partners from five European countries take part in this project: Construcciones y Obras Públicas y Civiles, S.A. (COPCISA, Spain), the Swedish National Road Administration (SNRA, Gestió d’Infraestructures S.A. (GISA), Società Italiana Macchine SpA (SIM), Wirtgen GmbH (Germany), Productos Asfálticos, S.A. (CEPSA-PROAS, Spain), Centre Internacional de Mètodes Numèrics en Enginyeria (CIMNE, Spain), Chalmers University of Technology (Sweden), Laboratori de Camins de la Universitat Politècnica de Catalunya (UPC, Spain), Belgian Road Research Centre (BRRC) and Laboratori General d’Assaigs i Investigacions (LGAI, Spain).

The aim of the project is to improve the materials, design and construction techniques for road rehabilitation using recycled asphalt mixes. For that purpose, experimental tracks were constructed in Spain and Sweden for hot and cold recycled mixes, where several mix formulae, selected from a preliminary laboratory study were produced and applied. A more detailed working plan is described in [1].

This paper specifically deals with the mix design of the hot mix asphalts and the performance based laboratory tests.

For the hot mix asphalts, it was decided to study two types of mixes, according to the Spanish tender specifications:

- a SMA-mix (type F10 in the Spanish tender specifications);
- an asphalt concrete mix (type S20 in the Spanish tender specifications);

In addition, a high modulus mix (type MAM in the Spanish specifications) was also considered. The composition of this high modulus mix is similar to the asphalt concrete mix of type S20, except for the higher binder and filler content.

For each mix type, two different percentages of reclaimed asphalt were considered: one "common" percentage (10 % for SMA and 30 % for the other mixes) and one high percentage (30 % for SMA and 50 % for the other mixes).

The sections, from which the RA was reclaimed, were of the same type as the new mixes. Up to now, the Spanish tender specifications have forbidden the use of recycled mixes for wearing layers, basically because it is obligatory to use granitic aggregates in wearing courses and, usually, the origin of the aggregates of reclaimed materials is not exactly known. For the experimental tracks of this project, it has been accepted to use recycling for the top layers only if the RA used in this layer was coming from another wearing course.

The mix formulae were established in close collaboration between BRRC and UPC. CEPSA contributed in the characterization of the constituent materials, primarily the binders. The analytical mix design was made according to BRRC's volumetric mix design procedure, implemented in the software PradoWin [2]. The analytical design was verified and optimized on the basis of the air void content of Marshall compacted specimens.

Finally, the designed hot mix asphalts were submitted to a series of performance related laboratory tests:

- Gyratory compaction to evaluate compactability of the mixes;
- Catalonian direct tensile test and three point bending fatigue test to evaluate durability;
- Wheel tracking test to evaluate rutting susceptibility.

Candidate binders for the hot mix asphalts were selected in a separate binder study, which was conducted in collaboration with CEPSA [3].

2. CHARACTERISTICS OF THE MIX CONSTITUENTS

2.1 Grading of RA and new aggregates

To start the mix design from reliable and representative data, it was decided to send the constituent materials to three different laboratories (UPC, CEPSA and BRRC). The new aggregates ("ARIDO", from Spanish origin), were provided in three fractions: 0/5, 5/12 and 12/25. Using the wet sieving procedure, the three labs obtained reproducible results for the grading. The average results are shown in table 1. Two types of reclaimed asphalt were provided: RA A, recovered from a SMA top layer, and RA B, recovered from a S20 asphalt concrete layer. After extracting the old binder from the reclaimed asphalt, the grading of the aggregates was measured. The results for RA A agreed reasonably well, both for the binder content and the aggregate grading. This material showed the presence of PmB's [3]. The results for RA B on the other hand were very different from one laboratory to another. A possible explanation for the anomalous results was given by the road contractor COPCISA: RA B was reclaimed from a layer that had been subject to many repairs over relatively large sections during its lifetime, so that the homogeneity of the material could be seriously doubted. As the mix design can not be based on unreliable data, it was decided that COPCISA would provide the laboratories with new material of the type RA B. This material was thoroughly homogenized and separated in three fractions as follows:

8-20 mm:	32.1%
4-8 mm:	27.5%
passing through 4 mm sieve:	39.4%

The three fractions were sent separately to the different laboratories. From this point on, the homogeneity of the reclaimed material RA B could be controlled in a better way and the three laboratories managed to obtain repeatable results. Table 1 also shows the average results, which were used as input data for the subsequent analytical mix design.

	ARIDO 12/25	***ARIDO 5/12***	***ARIDO 0/5***	***RA A***	***RA B***
Sieve (mm)	**% passing**				
25	100				
20	82				100
12.5	15	100		100	94.6
8	1	83	100	88.3	83.7
4	1	4.7	90.8	41.7	54.9
2	0.6	1.8	59.6	28.3	39.1
1	0.6	/	38.0	/	/
0.5	0.6	1.6	25.8	17.3	21.5
0.25	0.5	/	18.3	13.9	16.3
0.125	0.5	/	14.5	10.9	11.5
0.063	0.5	1.3	10.5	9.1	8.8
density (ton/m^3)	*2.714*	*2.681*	*2.679*	*/*	*/*
Binder content (% m)	*/*	*/*	*/*	*4.7 %*	*4.3 %*

Table 1: Grading and density of the new aggregates and reclaimed asphalt

The characteristics measured on the provided filler are shown in table 2.

Filler grading				**Density (ton/m³)**	**% of voids**
sieve (mm)	*0.25*	*0.125*	*0.063*	2.715	32.3
% passing	100	97	89		

Table 2: Characteristics of the new filler

2.2 Binder characteristics

The binders for the hot mix asphalts were selected in a separate binder study. They are shown in table 3

Mix type	Description	% RA	Binder type
SMA	Stone mastic asphalt 0/10	10 % RA	PmB without renewing agents PmB with renewing agents
		30 % RA	PmB without renewing agents PmB with renewing agents
S20	Asphalt concrete 0/20	30 % RA	B80/100 without renewing agents PmB without renewing agents
		50 % RA	B150/200 without renewing agents PmB without renewing agents PmB with 20 % renewing agents
MAM	High modulus asphalt concrete 0/20	30 % RA	PmB10/30-30%RA
		50 % RA	PmB10/30-50%RA

Table 3: Overview of the binders selected in the binder study (for more details see [3])

3. MIX DESIGN AND OPTIMIZATION

BRRC's software PradoWin [2] was used to perform the analytical mix design. The input data for the PradoWin calculations are:

- The characteristics of the constituent materials (binder, coarse aggregates, sand, filler and RA);
- The specifications of the mix (grading specifications, binder specifications, …).

The mix design procedure followed by PradoWin is briefly described below:
In a first step, the composition of the dry aggregate mix is tuned to meet the grading specifications. The grading of the dry aggregate mix is used to calculate the volume of the voids contained within the aggregate skeleton. The percentage of air voids in the asphalt mix can then be calculated for any percentage of binder content. If the air void percentage does not meet the specifications, the binder content or the composition of the dry aggregate mix can be tuned. Finally, PradoWin allows for the prediction of the most important mechanical properties of the asphalt mix, based on the volumetric composition and the binder characteristics.
The design of the hot mix asphalts for the Paramix project was made according to the Spanish tender specifications. Tables 4 and 5 show a summary of the relevant specifications. It should be noticed that the design aimed and succeeded in matching the grading curves of the mixes of the same type, but with different percentages of RA, very closely. This makes the comparison of their mechanical behaviour easier. The final compositions of the asphalt mixes designed by PradoWin are shown in table 6. Table 7 shows some additional results calculated by PradoWin.

Sieve (mm)	***25***	***20***	***12.5***	***10***	***8***	***4***	***2***	***0.5***	***0.25***	***0.125***	***0.063***
SMA				75-97	-	23-38	18-32	11-23	-	-	7-9
S20	100	80-95	64-79	-	50-66	35-50	24-38	11-21	7-15	5-10	3-7
MAM	100	80-95	64-79	-	50-66	35-50	24-38	11-21	8-15	7-12	6-9

Table 4: Grading specifications according to Spanish tender specifications (% of mass) passing through sieve

	SMA	**S20**	**MAM**
Minimum binder content (%m on 100 %m of dry aggregates)	5.5 %	4	5.2
Recommended filler/binder ratio (in mass)	1.4-1.8	1.2	1.3-1.5
% of voids (according to Marshall test)	>4 %	4-6	4-6

Table 5: Other important specifications according to Spanish tender specifications

	SMA		**S20**		**MAM**	
	10 % RA	*30 % RA*	*30 % RA*	*50 % RA*	*30 % RA*	*50 % RA*
New filler	4.4	3.5	0	0	2	1.5
Arido 12-25	38.6	36.1	38.6	36.1	39.6	39.0
Arido 5-12	58.8	47.4	6.9	2	8.6	0.0
Arido 0-5	26.8	19.1	24.5	11.9	19.8	9.5
RA	10.0	30.0	30.0	50.0	30.0	50.0

Table 6: Composition of the hot mix asphalts (in % mass)

	SMA		S20		MAM	
	10 % RA	*30 % RA*	*30 % RA*	*50 % RA*	*30 % RA*	*50 % RA*
Binder content (on 100 %m of dry aggregates)	5.7	5.5	4.5	4.5	5.2	5.2
Filler/binder ratio (in mass)	1.47	1.54	1.22	1.31	1.31	1.34
Maximum density (ton/m^3)	2.463	2.464	2.508	2.502	2.484	2.479
Calculated voids (%)	10.6	11.0	6.3	6.4	4.3	4.0

Table 7: Additional data calculated by PradoWin

The Spanish tender specifications are all satisfied by the mix designs. Only the calculated void percentage of the S20-mixes is higher than allowed by the Spanish specifications. This is the result of a design optimization procedure, based on the compaction of Marshall specimens. Table 8 gives the results for the Marshall voids. As can be seen in this table, the Marshall specimens of the S20-mixes revealed a void percentage which was systematically lower than the void percentage predicted by PradoWin. This could be explained by the fact that the Marshall compaction procedure used 75 blows, following the Spanish standards, while the PradoWin software was developed to predict the void percentage of Marshall specimens compacted with only 50 blows. This systematic discrepancy between predicted void content and measured void content was accounted for in the PradoWin study, by designing for a higher void percentage. In this way, the void percentage of the Marshall compacted specimens satisfies the specifications.

	SMA-10% RA		**SMA-30% RA**	
Binder	PmB without renewing agents	PmB with renewing agents	PmB without renewing agents	PmB with renewing agents
Marshall tests, using 50 blows (on 2 samples)				
mean	**7.9%**	**7.5%**	**8.7%**	**10.0%**
s.d.	1.9%	0%	0.6%	0.9%

	S20-30% RA	**S20-50% RA**
Binder	B80/100 without renewing agents	B150/200 without renewing agents
Marshall tests, using 75 blows (on 4 samples)		
average	**5.2%**	**4.7%**
s.d.	0.2%	0.4%

Table 8: Results of Marshall voids for SMA- and S20-mixtures

Marshall compaction can induce crushing of the larger aggregates, so that the grading becomes less discontinuous and the void percentage smaller than expected from the theoretical mix design. Mixes with a stony skeleton, like SMA, are particularly sensitive to this. To investigate this effect, the aggregates from Marshall compacted samples of the SMA-mix were recovered and the grading was measured using wet sieving. The results are shown in figure 1. It is indeed observed that the grading of the aggregates from the Marshall compacted samples is less steep than the grading calculated using PradoWin. This confirms the fact that aggregate crushing takes place and explains why the void percentages predicted by PradoWin are higher than the void percentages measured on the Marshall samples. The effect of aggregate crushing is also larger for the 10 % RA mix than for the 30 % RA. This is in agreement with an observation made in the laboratory: the new aggregates were very brittle and could be broken without too much effort.

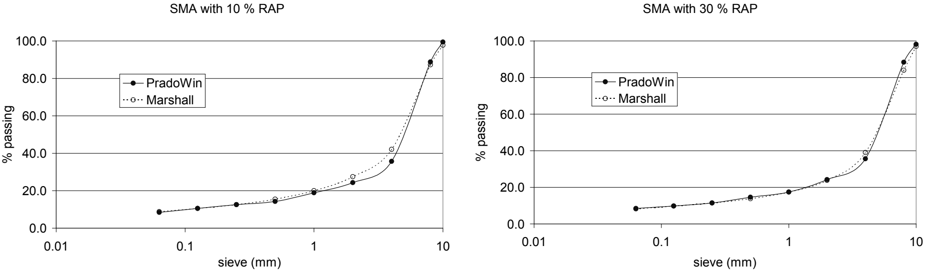

Figure 1: Grading of the aggregates after recovery from the laboratory Marshall compacted SMA samples

4. PERFORMANCE TESTING

4.1. Compactability

Gyratory compaction was performed by BRRC to evaluate the compactability and the influence of the binder on compactability. The gyratory tests were made according to the draft European norm prEN 12697-31. In combination with the binders shown in table 3, four SMA-mixes and five S20-mixes were investigated.

The SMA-mixes were compacted in the 100 mm diameter mould. Three samples were compacted for each mix. Figure 2 shows the average curves of the air voids as function of the number of gyrations.

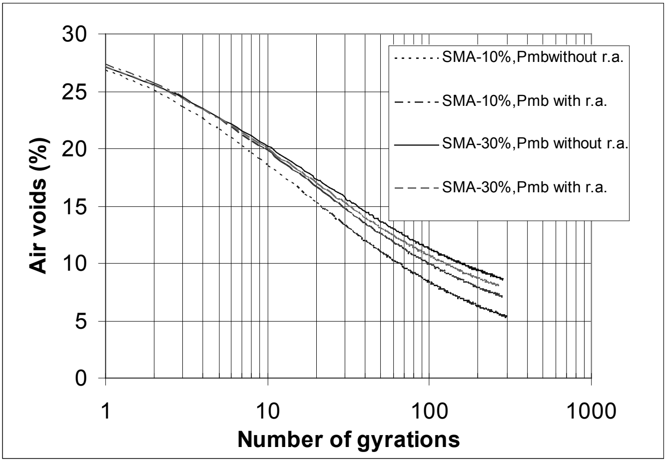

Figure 2: Air voids as function of the number of gyrations for the SMA-mixes

PradoWin predicted a higher void content for the 30 % RA mixes than for the 10 % RA mixes. The gyratory tests also reveal a slightly higher void content in the 30 % RA mixes, but the difference between the air void curves is higher than the predicted 0.4 %. This can be explained by the binder viscosity, which is lower for the 10 % RA mixes. Consequently, the mixes with 10 % RA are compacted more easily.

Of the two mixes with 10 % RA, the mix prepared with the PmB with renewing agents shows a slightly higher percentage of air voids in the gyratory compactor. Again, the viscosity of this binder is slightly higher (see [3]).

The S20-mixes were compacted in the 150 mm diameter mould, as prescribed for mixes containing aggregates larger than 16 mm. Four repeated measurements were made for each mix. Figure 3 shows the average curves.

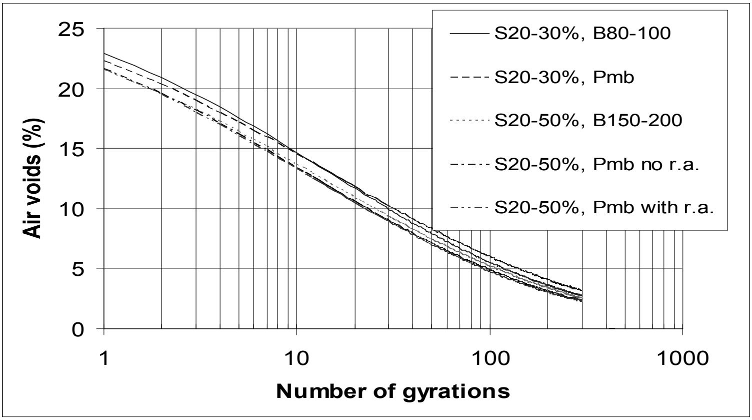

Figure 3: Air voids as function of the number of gyrations for the S-20 mixes with 30 % and 50 % RA

For the S20-mixes, no significant differences were observed in the gyratory curves. In this study, the compactability is thus the same for the pure binders and the PmB binders. The renewing agent also has no effect on the compactability.

4.2. Fatigue behaviour

One of the important requirements of bituminous mixtures is its resistance to fatigue. However, this property is not taken into account in the mix design when the optimal binder content or the grading curves are selected. This is basically due to the complexity of the fatigue tests which are normally not used in the design phase. For these reasons, the road laboratory of the Technical University of Catalonia has developed a new procedure that has been applied in the Paramix project, which tries to relate the tensile fracture mechanical characteristics of the tensile test to the fatigue behaviour of the bituminous mix.

4.2.1. Direct tensile test CTD

The CTD-test (Catalonian direct tensile test) consists in breaking a prismatic specimen of a bituminous mix at a constant speed of 0.1 mm/min and at a temperature of 20ºC. With these test conditions, the mixes show a ductile and tough behaviour and it is possible to determine these characteristics for a given mix. In figure 4, the results of the S20-mixes and high modulus mixes are represented. It is clear from this figure that the high modulus mixes show a more brittle behaviour, with a higher maximum load. This can be explained by the high stiffness of the new binders, combined with the use of RA. The S20-mixtures with use of RA show a more ductile behaviour with a lower maximum strength when less RA is used. The reference mixture without RA showed the most ductile behaviour, with the lowest strength. It is interesting that the effect of the use of RA on the ductility and maximum strength is limited in this study, because soft binders have been added to balance the hard and brittle binder of the RA.

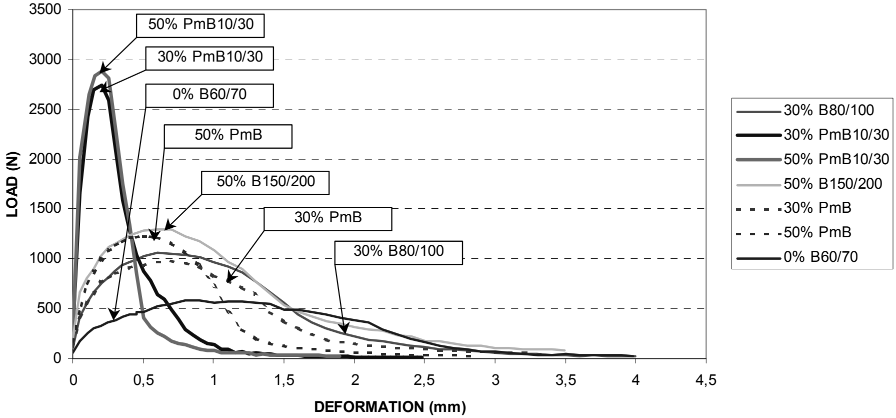

Figure 4: Direct tensile test results for all types of S20-mixes studied.

4.2.2. Three point bending fatigue testing

Fatigue testing has been performed using the three-point bending fatigue test. The tests were carried out in the dispacement controlled mode at a temperature of 20ºC and at a frequency of 10 Hz. In this test, the fatigue curves (figure 5), and the evolution of the deformation in the inferior fibre of the specimen (figure 6) have been determined.

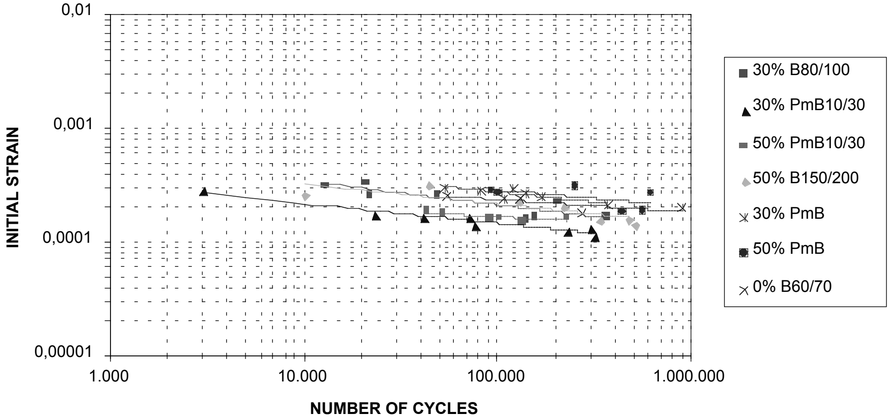

Figure 5: Fatigue laws obtained with the three-point bending beam test

Figure 5 indicates that both high stiffness mixes performed less good in fatigue. The other mixtures showed a comparable fatigue performance, at least within the precision of the test. In figure 6 the evolution of the deformation in the inferior fibre during the test is shown for a number of specimens of the same mixture. For each mix type, the mean deformation at failure by fatigue has been determined, taking for each tested specimen the deformation at failure as the crossing point of the two tangents of the strain evolution curve.

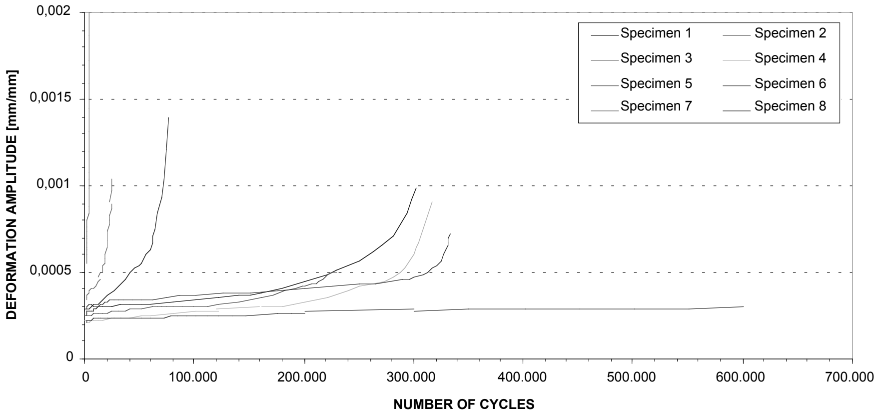

Figure 6: Deformation in the inferior fibre as a function of the number of load applications

In figure 7, the fatigue behaviour has been represented in another format, putting in the abscissa the logarithm of the number of load applications until fatigue failure, and in the ordinate the quotient between the initial imposed strain and the critical strain (i.e. the mean deformations at failure). In this representation, the fatigue laws arrange in accordance with the modulus value, forming a fan where the mixes with a higher modulus are in the upper part and the slope is lower. The results in figure 7 show a similar behaviour for the mix made with virgin materials to the mixes where RA has been used.

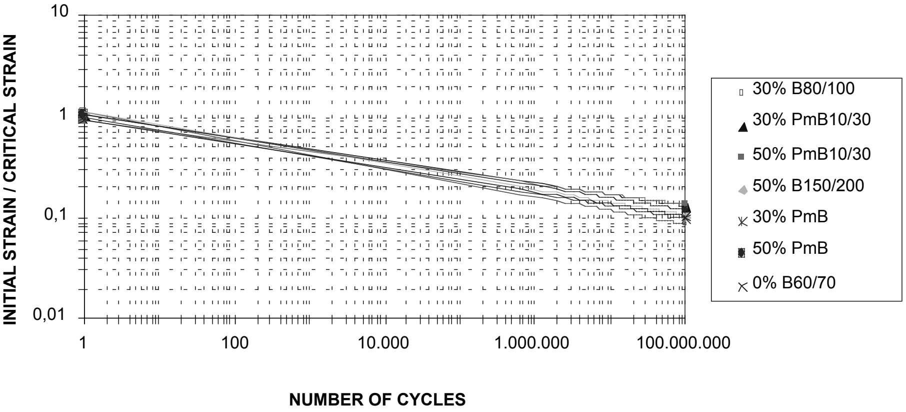

Figure 7: Representation of the fatigue curves in terms of deformation in the inferior fibre of the specimen

Furthermore, it is interesting to note that a good correlation was obtained between the deformation at maximum strength of the mix in the static mode, as determined by the CTD test, and the final fatigue deformation. This can be observed in figure 8. Also, there is a good correlation between the stiffness modulus of the mix in the CTD- test and the dynamic modulus of the mix determined by the three point bending fatigue test, as can be seen in figure 9.

Both observations permit, as was published before by UPC, to make an estimate of the fatigue behaviour of the mixes with an easy static tensile test, CTD test, which facilitates the consideration of this property in the mix design. Indeed, to improve the fatigue response of the mix, it is necessary to increase its stiffness modulus and its deformation at failure. For mixes with a similar modulus, the fatigue behaviour is better as the deformation at failure in the CTD test increases. For mixes with a similar deformation at failure, their fatigue response in an actual road construction is better as the stiffness modulus of the material increases (the strains are lower).

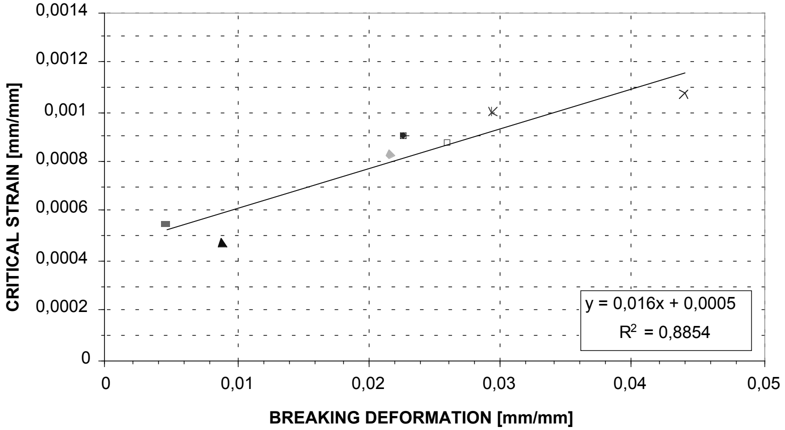

Figure 8: Correlation between the breaking deformation and the critical strain.

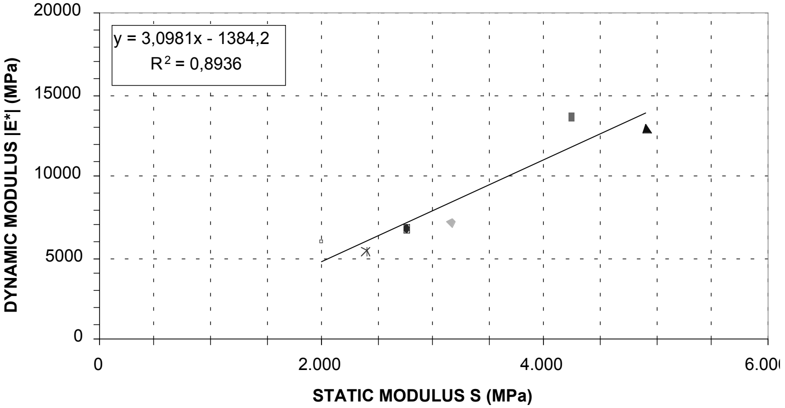

Figure 9: Correlation between the static modulus and the dynamic modulus.

4.3. Rutting susceptibility

Wheel tracking tests were performed with a large size device according to the draft European norm prEN 12697-22, at a temperature of 50 °C. The test samples were compacted using the plate compactor according to prEN 12697-33.

Two samples were tested per mix. The average curves are plotted in figure 10 for the SMA-mixes and figure 11 for the S20-mixes.

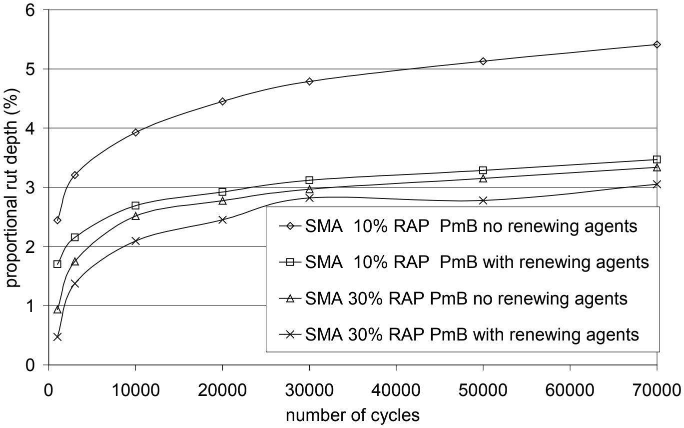

Figure 10: Wheel tracking tests on SMA-mixes

The following conclusions can be drawn for the SMA-mixes:

- The SMA-mixes perform well in the wheel tracking test. According to the present Belgian standards, they belong to the best category for rutting resistance. This can be attributed to the stable stony skeleton and the relatively high percentage of air voids.
- The difference in percentage of RA and the difference between the binders with and without renewing agents seem to have no impact on the ranking of the test results. This is explained by the fact that the mix gradings and binder content of the mixtures with and without RA were the same and that all binders were selected to obtain a similar rheological behaviour when mixed with the old binder in the RA (see Paramix binder study [3]).
- The SMA-mix with 10 % RA without renewing agents showed the lowest rutting resistance. However, this was not reflected in the binder stiffness measurements at high temperatures as this binder showed the highest binder stiffness value (about 50 % higher than that of the other binders) [3].

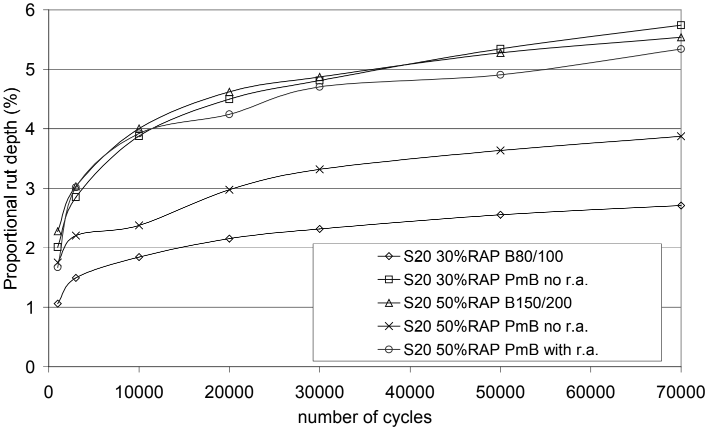

Figure 11: Wheel tracking tests on S20-mixes

For the S20-mixtures, the following observations can be made:

- The S20-mixes also perform very well in rutting. According to the present Belgian classification, they also belong to the best category.
- As for the SMA-mixes, there is no impact of the percentage of RA on the rutting results. The PmB's do not improve the results of the test, when compared to the pure binders. There are two possible explanations for this. First of all, the aggregate skeleton itself is very stable and resistant to rutting; variations in the binder become less apparent in such cases. Secondly, the rheological characteristics of the binders were not too different, as shown in [3]. Hence, the wheel tracking test is not sensitive enough to reflect these changes. We note also that the test temperature of 50 °C and the test frequency of 1 Hz are not optimal for discriminating PmB's and pure binders of the same grade, as PmB's improve the rutting resistance especially at high temperatures and low frequencies. It is possible that at higher temperatures and very low traffic speed, the PmB's will perform better than the pure binders.
- The mix with the renewing agent performed not significantly different than the comparable mix without renewing agent.

5. CONCLUSIONS

A sound design procedure allows for the design of high quality hot mix asphalts with high percentages of reclaimed asphalt. As the design depends on the characteristics of the constituent materials, it is important to start from reliable material data. The present project showed that this is particularly difficult for the reclaimed asphalt. A thorough homogenization of the RA is absolutely necessary. Evidently, the higher the percentage of RA, the more stringent this condition will become.

The performance related laboratory tests showed no relevant differences between the mixes with "common" percentages of RA and those with "high" percentages of RA. Hence, from a laboratory point of view, it is shown that the amount of RA used in hot asphalt mixes can be increased without affecting the performance of these mixes, of course under the conditions that a suitable grading curve can be found and that the new binders are well selected .

The performance tests were also not capable of distinguishing between similar mixes, with and without renewing agents in the binder.

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REFERENCES

[1] M. Bou Jové and L. De Bock, "The PARAMIX project: enhanced recycling techniques for asphalt pavements", proceedings of the Fifth Intern. Conference on the Environmental and Technical Implications of Construction with Alternative Materials WASCON 2003, San Sebastian , Spain, 4 - 6 June 2003. Proceedings edited by G. Ortiz de Rubina - INASMET and J.J.J.M. Goumans - ISCOWA.

[2] L. Francken, A. Vanelstraete, D. Léonard and O. Pilate, "New developments in the PRADO volumetric mix design", Proc. Of the 6th RILEM Symposium on Performance Testing and Evaluation of Bituminous Materials, PTEBM'03, pp. 292

[3] A. Vanelstraete, J. De Visscher, M. Fernandez, J.A. Soto, L. De Bock, "Selection of binders for asphalt mixes with reclaimed asphalt as studied in the PARAMIX project", this conference

[4] F. Pérez-Jiménez, M. Rodríguez-Cambeiro, R. Miró-Recasens, "Influence of the Failure Criteria in the Fatigue Laws using the Three-Point Bending Beam Test", sent for the 2004 TRB annual meeting.

[5] prEN13108-1 draft European standard, "Bituminous mixes – Material specifications - Part 1. Asphalt concrete".