High stiffness underlayers with high percentage of re-use as developed in the NR2C-project

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ABSTRACT:
New Road Construction Concepts (NR2C) is a FEHRL-project supported by the European Commission under the Sixth Framework Programme. NR2C aims at developing perspectives and specific innovations in different areas. One of the ideas concerns the development of high performance underlayers with high percentage of reclaimed asphalt.
Three different mixes were designed, optimized and compared, namely with 0 %, 25 % and 40 % reclaimed asphalt. After an extensive laboratory study, the selected solutions have been further studied in a full-scale ALT facility. The structure tested has been instrumented with strain gauges, deflection and temperature sensors in order to analyse the performances. In a first step, fatigue behaviour was evaluated by applying 100'000 12-tons axle loads at 15 °C. Then, low temperature behaviour was investigated by load applications during a number of temperature cycles where the air temperature varied between +2 °C and -7 °C. In addition to the ALT, tests on large slabs with extreme temperature and other laboratory tests on mixes and binders have been performed.
Finally, no negative effect using a high percentage of reclaimed asphalt has been found within this study. However key parameters as for instance the mix design and RA properties require special attention.

1. Introduction

The NR2C-project (which stands for New Road Construction Concepts) is a project of FEHRL supported by the European Commission under the Sixth Framework Programme. NR2C developed long-term visions for road infrastructure and carried out some specific innovations, in which long-term visions and ideas are linked to short-term actions [1]. One of the ideas in the framework of sustainable road construction worked out in NR2C concerned the development of high stiffness base layers with high percentages of re-use materials. Although high stiffness base layers are already extensively used in some European countries, such as France, the experience with re-use in such mixtures is still very limited. There is indeed a fear for a limited durability of these mixtures because of the combination of a hard binder (which is typical for these mixtures) and re-use material.

This project aimed to optimize the design of these mixes so as to guarantee their long-term performance, even with high percentages of reclaimed asphalt. This was achieved by both a laboratory and an ALT-study (ALT= accelerated loading testing). The project was carried out by several partners. BRRC took care of the material characterization, the mix design and the laboratory performance studies prior to ALT-testing. LAVOC was in charge of the realisation, instrumentation and testing of the experimental ALT-sections. VTI, DRI and KTI carried out the subsequent testing of material taken from ALT-sections. This paper gives a summary of the results.

2. Material characterisation and mix design

High stiffness modulus mixes were prepared with Belgian as well as with Swiss materials. One and the same hard binder 10/20 was used through the whole study. Its characteristics are given in table 1 [2]. The mixes with the Belgian materials were used for extensive laboratory testing. These tests provided information for the designs to be made with the Swiss materials, which were applied on the LAVOC ALT facility.

Table 1: Characteristics of the hard binder 10/20.

Pen (25°C) [1/10 mm]	R & B [°C]	G* (at 1.6 Hz) [Mpa]			Zero shear viscosity– EVT 2 (prEN 15324) [°C]	Temperature for 1 % failure strain in Direct tension test[°C]
		50°C	15°C	0°C		
16	70.2	0.273	27.0	152	73.2	-8.1

The BRRC software PradoWin was used for the mix designs and optimization. PradoWin is a user-friendly program, adapted for the volumetric mix design of bituminous mixtures, and with a special feature to facilitate the mix design of mixtures with re-use materials. The required input data are the characteristics of the constituent materials. For both Belgian and Swiss materials the following characteristics were measured in the laboratory of BRRC:

- On the aggregates (sand and stones): grading, density.
- On the filler: grading, density, voids Rigden.
- On the reclaimed asphalt: grading, density, binder content, R&B and pen on recovered binder. Results are given in [3].The characteristics of the recovered binder are given in table 2.

Table 2: Characteristics of the recovered binder of the reclaimed asphalt

Type	Pen [1/10mm]	R & B [°C]	%
Belgian RA	17	67.3	5.5
Swiss RA	32	59.4	4.8

High stiffness mixtures for base layers can be achieved by using a high percentage of stones and a hard binder. Together with an increased binder content compared to a conventional asphalt composition suitable for base layers, this allows to design, despite of the high percentage of stones, relatively dense mixtures with a good coating of the aggregates and hence, a good performance in durability.

Two basic mix designs were made:

- one mix design with Belgian materials,
- one mix design with the Swiss materials to be used in the ALT study.

Different variants (with different percentages of RA) were designed, based on approximately the same grading curve:

- Variant 1: Design without RA (reference).
- Variant 2: Design with 25 % RA.
- Variant 3: Design with 40 % RA.

The analytical mix design was combined with subsequent gyratory compaction tests according to EN12697-31 to verify the compactability and the air void content. Depending on the results of the gyratory tests, the analytical mix design was adapted.

Table 3 shows the final mix gradings for the various variants. The percentage of RA given in table 3 stands for the percentage of old binder (from RA) on the total binder content.

Table 3: Grading of the different mixtures

	Mixes with Belgian materials			Mixes with Swiss materials		
% RA	0	25	40	0	25	40
% total binder	5.5	5.5	5.5	5.8	5.8	5.8
% RA aggregates	0	24.3	39.4	0	29.5	47.4
% passing on sieve:						
20 mm	100	100	100	100	100	100
14 mm	97.3	96.8	96.4	97.7	97.0	96.7
10 mm	75.4	75.5	74.9	76.4	76.2	79.2
6.3 mm	52.1	53.9	54.1	57.5	55.3	59.5
4 mm	37.9	40.3	41.1	43.8	41.5	45.1
2 mm	30.5	32.0	32.3	33.0	30.3	32.1
1 mm	21.9	24.6	25.8	25.6	22.7	23.2
0.5 mm	16.0	18.9	20.5	21.2	17.9	17.5
0.25 mm	11.1	13.1	14.2	17.5	14.1	13.0
0.063 mm	5.9	6.0	6.1	6.3	6.3	6.4

3. Laboratory performance of the mixes

A laboratory study was then performed on all mixtures to check the laboratory performances:

- Stiffness modulus was determined according to EN12697-26 annex A (two-point bending test on trapezoidal samples) for temperatures between -20 °C and 30 °C and for frequencies between 1 and 30 Hz. Two samples were tested per mix.
- Resistance to fatigue of the different mixes was determined according to the BRRC-method [4] (two point bending test on trapezoidal samples) at 15 °C and 10 Hz. This test method is close to EN12697-24 annex A, but is stress controlled and is performed on large samples. Twelve to sixteen samples were tested per mix. As fatigue measurements are very time consuming only the mixes with 0 and 40 % RA were fully tested in fatigue.
- Resistance to permanent deformation is determined according to EN12697-22 (large device in air) at a temperature of 50 °C. Two samples were tested per mix. Resistance to permanent deformation was not determined for the Belgian mixes with RA. As the binder of the reclaimed asphalt is very hard and comparable to the new binder (see table 2), permanent deformation was not considered as a risk for these mixes.
- Water sensitivity is determined as the indirect tensile strength according to EN12697-23 before and after conditioning in water according to EN12697-12. Five samples were tested per mix.

The results are given in table 4. We note that for the Swiss mixtures with RA, some of the tests were performed with a lower binder content (5.7 and 5.6 % for 25 % and 40 % of RA respectively, instead of 5.8 %). The reason for this is that in an asphalt plant, the variations on binder content of RA are usually larger than in the laboratory. With a high percentage of re-use, the impact of this parameter on the total binder content is important. A way to deal with this uncertainty in the phase of mechanical performance testing is to make the tests with the most unfavourable estimation of the binder content. For the mix with 40 % of RA, a variation of 0.5 % on the binder content of the RA would lead to a variation of 0.2 % on the total binder content. By doing some tests with a total binder content of 5.6 % instead of 5.8 %, the laboratory tests will be on the safe side.

Table 4: Laboratory performance of the different variants

	Mixes with Belgian materials			Mixes with Swiss materials		
% RA	0	25	40	0	25	40
% total binder	5.5	5.5	5.5	5.8	5.8	5.8
% voids gyratory (100 gyr.)	3.3	3.8	2.7	3.3	3.2	1.8
Rut depth [%] at 30000 cycles, 50 °C	2.7	-	-	3.0	2.5	2.8
ITS-testing Voids [%] (hydrostatic) Strength before [Mpa] ITS-ratio	 3.3 2.5 98 %	 2.8 2.3 95 %	 2.4 2.4 101%	 3.7 2.3 92 %	 5.0 (*) 1.5 (*) 104%(*)	 6.0 (**) 1.3(**) 94 %(**)
Stiffness modulus [Mpa] at 15 °C - 10 Hz	12740	-	12830	13900	12460 (*)	12050
Fatigue [15 °C, 10 Hz] Slope a ε6 (µstrain) N for ε = 120 µstrain	 0.156 123.4 1.2×10^6	 - - 	 0.146 120.1 1.0×10^6	 0.097 143.2 6.2×10^6	 - - -	 0.131 123.7 1.3×10^6

(*) determined for 5.7 % binder content instead of 5.8 % to investigate the risk of durability
(**) determined for 5.6 % binder content instead of 5.8 % to investigate the risk of durability

It can be observed that a high performance was reached on all aspects:

- All mixes have a very high stiffness around 12000 - 13000 MPa at 15 °C and 10 Hz.
- The resistance to permanent deformation is very high: always below 5 %. Note that this is the lowest value (best performance) according to the European specifications in EN1308-1.
- The resistance to the action of water is very high: for all mixes above 90 %, which shows that durability problems are not to be expected.
- The resistance to fatigue is very high: above 1.0×10^6 cycles at 120 microstrain. This is at least a factor seven better than a conventional Belgian mix for underlayers.
- The void content (measured hydrostatically) of the Swiss mixes with 25 % (binder content 5.7 %) and 40 % RA (binder content 5.6 %) is rather high: 5 % respectively 6 %.
- Mixes with reclaimed asphalt have generally equivalent performance as mixes without RA, expect for the mix with 40 % RA with Swiss materials for which a reduction in lifetime was observed. Its lifetime was still comparable to that of all mixes with Belgian materials.

It was concluded that the designed mixtures with the Swiss materials can be used for the ALT-study.

4. Accelerated loading tests

In a first phase, accelerated loading tests have been performed in LAVOC's full-scale facility. These tests are presented in this chapter. In addition to the ALT, some other tests on in situ mixes have been performed with the aim of providing additional information for a better performance analysis. These tests are presented in chapter 5.

4.1 Accelerated loading tests setup

The selected solutions were tested in full-scale accelerated loading testing (ALT) facility of LAVOC. They have been applied in a test section which dimensions are 13.1 m x 5.4 m (circulation direction). The pavement design has been performed using two specific pavement design softwares based on the multilayer theory of Burmister. The calculation has been conducted first with the Belgian software DimMET, developed by BRRC and Febelcem for the MET (Wallon Ministry of Equipment). Secondly, another calculation according to the French design method with the help of the NOAH software has been performed. For this pavement design, the aim was to have a structure which is expected to reach the end of its design life after 2/3 of the planned passages. More details can be found in [5].

The tested structure, represented in figure 1, is as follows:

- Layer 1: AC MR8 (3 cm),
- Layer 2: High Stiffness Modulus (8 cm),
- Layer 3: Soil foundation composed by gravel 0/60 (40 cm), fine Sand (145 cm) and Concrete.

Four different sections have been studied for the HMA: a reference without RA (field 0), a section with 25 % of RA (field 1) and two sections with 40 % of RA of which one doesn't include a wearing course (field 3).

The sections have then been loaded with a heavy traffic simulator (axle load of 12 tons, tyre pressure of 0.8 MPa), which simulates traffic close to in situ conditions.

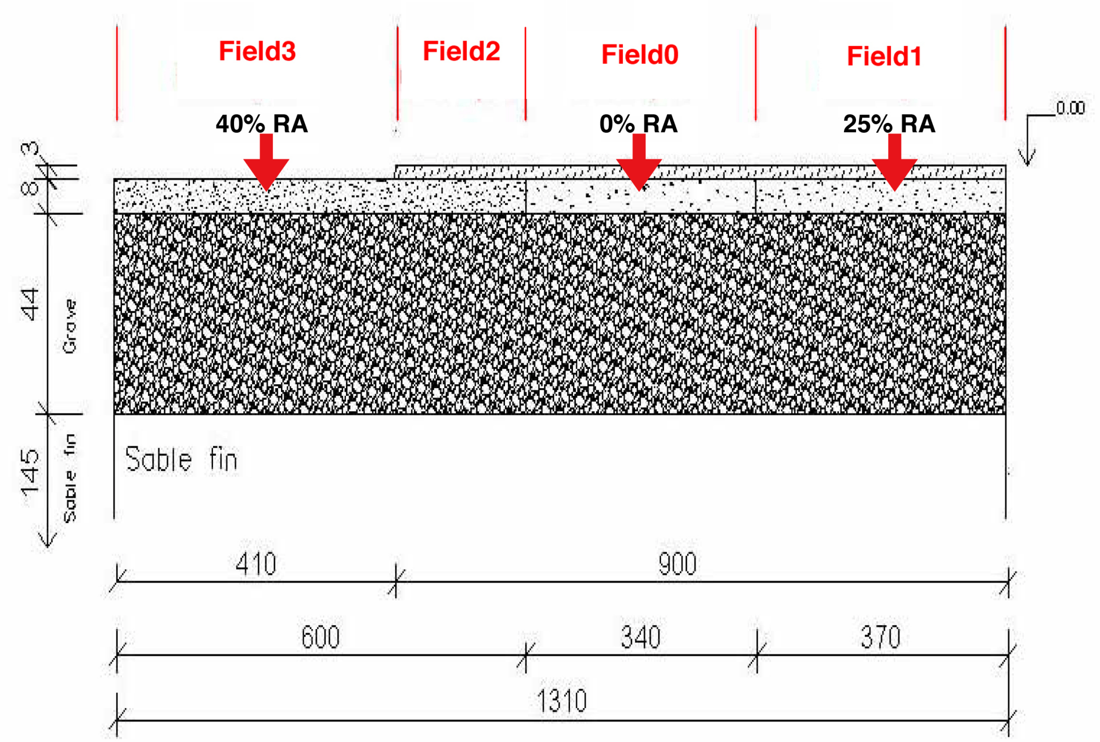

Figure 1: Cross section view of the tested pavement

In order to measure horizontal stress and strain as well as temperature, different sensors have been installed at the bottom of the HMA and also at the interface between HMA and top layer. Four temperature measurements classical Pt100 have been installed at different depths. Deformation measurements have been achieved using KYOWA strain gauges. A total number of 57 sensors have been installed in the pavement.

In addition to these sensors, surface deflection has been measured using a specific deflection beam instrumented with LVDT sensors (Figure 2). Using this device, measurements close to the wheel passage have been conducted.

Figure 2: Specific deflection beam used in the ALT facility

In order to tests the different pavement types, three positions of circulation have been defined (figure 3):

- Position A: Two wheels on field 3 with 40 % RA, no top layer (axles A1 and A2)
- Position B: One wheel on field 2 with 40 % RA (axle B1) and one wheel on reference field 0 (axle C1)
- Position C: One wheel on the reference field (axle C2) and one wheel on the field 1 with 25 % RA (axle D1)

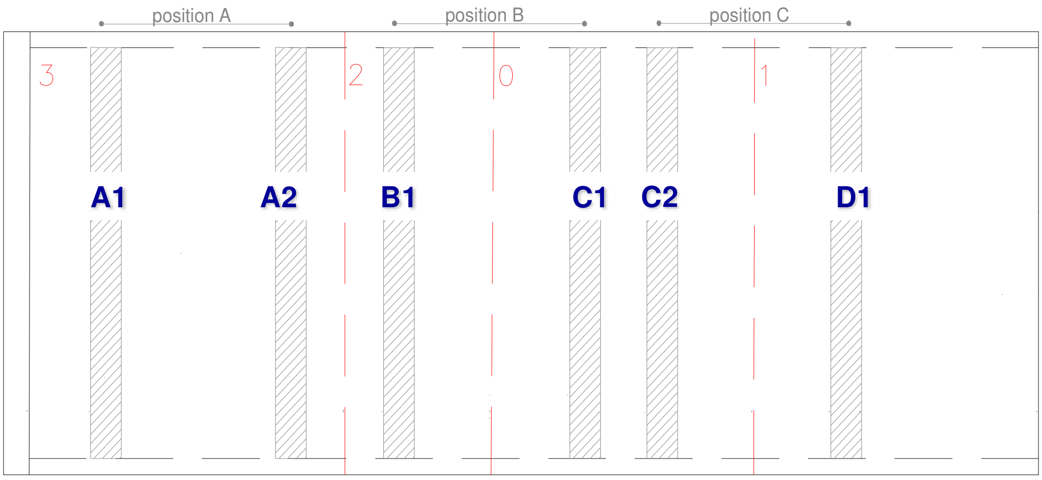

Figure 3: Positions of circulation for ALT testing

The behaviour of the different sections has been assessed through two following test phases. In a first part, fatigue tests have been performed at a constant air temperature of 15 ℃. During these fatigue tests, about 100'000 wheel passages have been performed on each position except position A that has got a total of 190'000 fatigue passages. These tests have been followed by low temperature tests. The aim of the second test phase was to simulate temperature cycles with circulation as well. Hence, it has been chosen to apply air temperature variations between 2 ℃ and -7 ℃ during 12 day for each position. In order to have a good temperature control, an isolated cabin with a cooling system using ventilators has been applied.

Using the instrumentation mentioned above and the load and temperature cycles as well, the mechanical behaviour of the different mixes have been assessed in an accelerated way.

4.2. Results and analysis of the ALT

The results are presented hereafter for the two test phases i.e. fatigue and low temperature tests. A total of more than 370 measurements have been performed during the whole test duration. The different raw data samples have been treated in a first phase, this in order to obtain the maximal deformation amplitude for each measurement. For an assessment of the fatigue resistance of the different mixtures, a special emphasis has been put on the deformations at the bottom of the asphalt layer. Indeed traction is most important at the bottom of the HMA and fatigue cracking will most likely occur at this interface [6].

In a first step, a specific analysis has been conducted for each axle separately, this in order to identify the order of magnitude of the measurements and the possible strain gauges problems or deviations as well. Then, comparisons between the different mixtures have been conducted. Indeed, an aim of this research was to assess if there is any negative effect using mixes with a high percentage of reclaimed asphalt instead of a mixture without RA. We can notice that parts of the results are presented hereafter. More details can be found in [7]

Comparison between 25 % and 0 % RA

The measurements performed in position C permit to make a comparison between the section with 25 % recycling material and the reference section without RA. In following figure 4, the third part of the gauge code indicates the measurement axle (C2 or D1). The first 100'000 passages correspond to the fatigue tests at 15 °C while the passages performed between 100'000 and 210'000 correspond to the low temperature tests (LT). We can notice that the general order of magnitude for the deformation decreases during the low temperature tests. This was expected because by reducing the temperature, the pavement becomes stiffer and consequently the deformation decreases. In figure 4 below, it is clear that the general trend is the same for both axles i.e. both mixes. However, the deformations measured on the section with 25 % RA are slightly lower than the measurements on the reference mix. Anyway, these differences are not significant to conclude for a much better behaviour of the section with 25 % RA, but show that its resistance is at least the same as that of the reference mix.

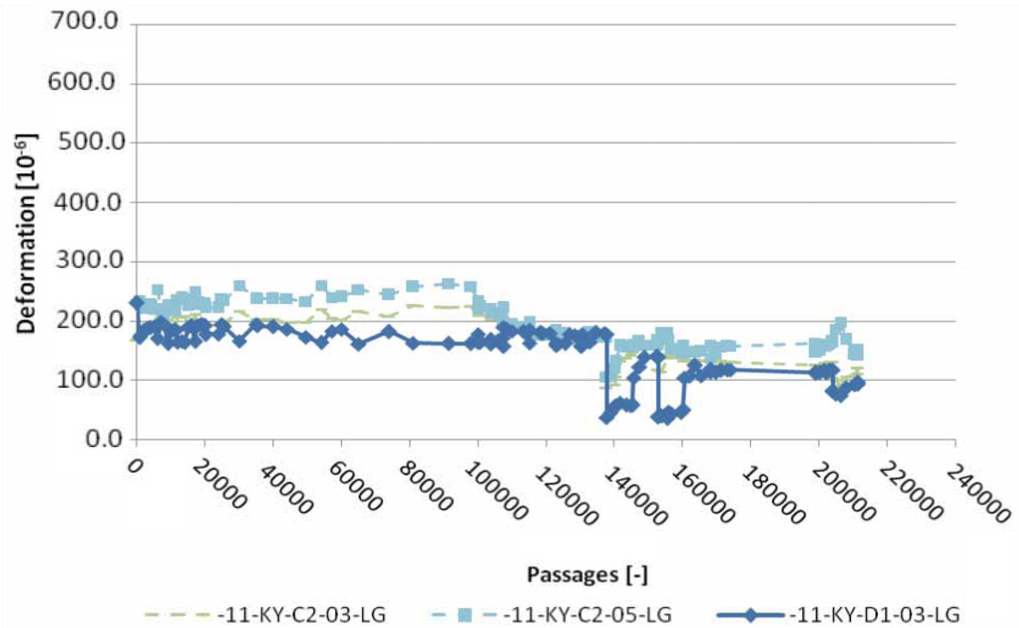

Figure 4: Comparison between axle C2 (2 equivalent sensors) for 0 % RA and axle D1 (25% RA)

Comparison between 40 % and 0 % RA
Using the measurements made on position B, a comparison between the section with 40 % RA (axle B1) and the reference section (axle C1) has been conducted. In figure 5 below, the strain gauges corresponding to axle C1 are represented with a discontinuous line. Comparing with figure 4 above, we can notice that more strain gauges are represented. The reason is that quite all the sensors worked during the whole tests duration on this position as only two strain gauges failed, this despite the severe conditions. As in previous case, the general trend shows a decreasing of the deformation during low temperature tests (between 100'000 and 190'000 passages) but the order of magnitude is slightly bigger than for previous comparison with deformation up to 300 µε. Comparing both mixes, the measurements on the section with the reference mix are a bit lower than with the mix containing 40 % recycling material. However, the differences measured are very small and they cannot be considered as a conclusion about a behaviour difference between the mixes.

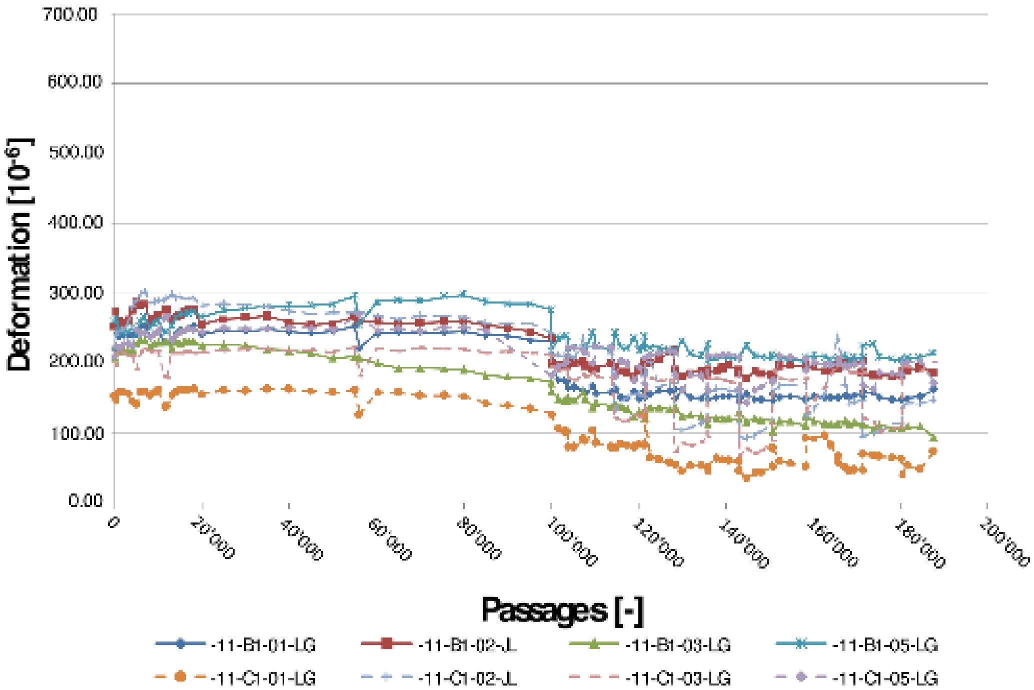

Figure 5: Comparison between axle C1 (0 % RA) and B1 (40 % RA)

Considering both comparisons above between the different mixes, we can conclude that the same order of magnitude has been measured for the deformation in the mixes without and with RA. The general trend of slightly lower deformation in the section with 25 % RA is not sufficient enough in order to deduce a difference in fatigue resistance. Moreover, it is important to keep in mind that even with the same testing program, it may be that the pavement temperatures are a bit different between two cases.

Comparison of the surface deflections
As mentioned in introduction, deflections have been measured during the circulation, at the top of the pavement, using LVDT sensors. Three different sensors have been placed respectively at 9 cm, 14 cm and 38 cm of the wheel passage.

The figure 6 below show the differences in the surface deflections registered for each mix for the sensor placed at 9 cm of the wheel passage. Concerning this figure, we have to mention that the sensor in position A (40 % RA) was on the section without top layer because of the test setup. Hence, it was expected to register higher deflections for the thinner pavement without wearing course. Moreover, as already explained the first 100'000 passages (190'000 for position A) correspond to fatigue tests with a constant temperature and the rests of the tests are low temperature tests with air temperature variations between 2 °C and -7 °C. Otherwise the deformations are rather comparable between the position B (reference mix) and C (mix with 25 % RA) with still slightly lower deflection on the section with 25 % recycling material. However, these measurements rather highlight the good behaviour of the structure with reclaimed asphalt in comparison with the reference mix as no big difference has been observed in surface deflection.

Concerning the surface deflection and deformations measured, a representation of both measurements permitted also to make a link between both measurements. Hence, with a more detailed analysis, a correlation law could be deduced.

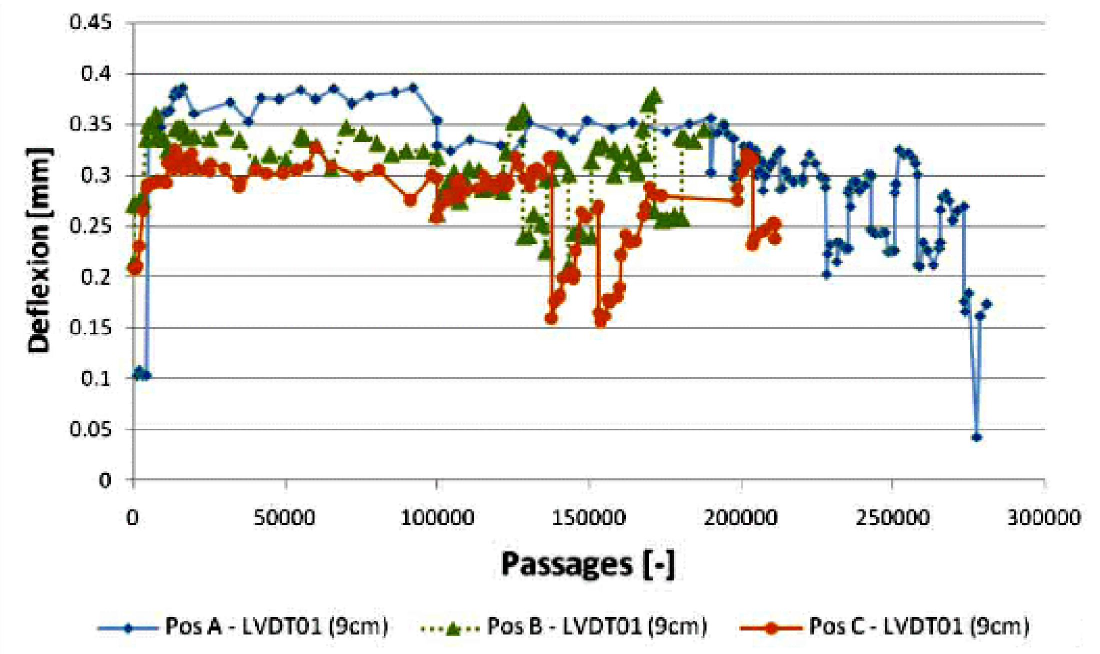

Figure 6: Comparison between the surface deflections registered

In addition to the different measurements, some calculations have been performed using the NOAH software at the end of the tests. The aim of these calculations was to have some additional information about the different material behaviour and an assessment of the difference between calculations and measurements.

For this part of the study, updated values obtained through laboratory tests have been considered in order to have accurate material characteristics. Moreover, a few points with stabilized temperature have been chosen and the calculation compared with the measurements for these selected points, considering the elastic modulus in function of the layer's temperature registered.

The outputs of these calculations were very interesting and quite good correlations with measurements have been found. In some cases less than 15 % difference has been calculated. Considering all the input parameters that influence the calculation (in situ material not necessary the same as laboratory samples, consideration of fatigue, Burmister theory, ..) the results obtained are in good agreement with the measurements. Moreover, the additional calculation permitted to make some sensitivity analysis on the bonding conditions or the effect of the top layer.

Following Figure 7 gives an example of the calculation results. In this figure, the calculated points are represented with red dots.

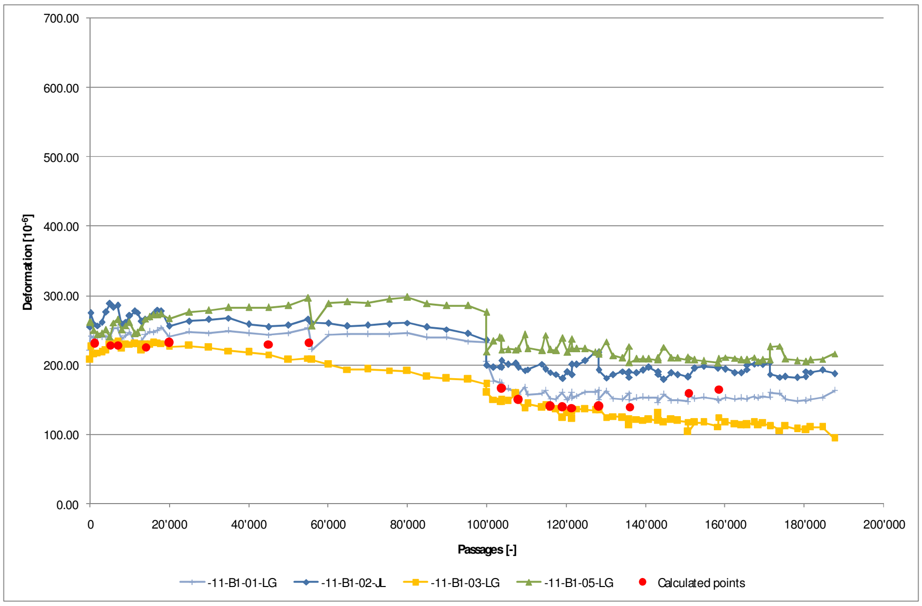

Figure 7: Comparison between calculated and measured points for axle B1 (40 % RA)

Finally, from the ALT study and additional calculations, no negative effect of a high percentage of RA has been observed. Indeed, the mixes with RA showed at least equal performance as the mix without recycling material. Moreover, the tests conducted reached a performance rate and load repetition that is high enough for concluding that the behaviour of the mixes is very good.

5. Structural behaviour assessment

5.1 Additional tests performed on the mixes

In addition to the ALT, some other tests and analysis have been selected and performed on in situ mixes as well. The aim of these tests was to provide some additional information, but always with the idea to assess the effect of a high percentage of reclaimed asphalt. The different additional tests performed are introduced hereafter while only the last one will be more detailed and the results presented. All the detailed results can be found in [7].

As already mentioned, wheel tracking tests have been conducted on laboratory mixes during the mix design. In order to assess the resistance to rutting of the in situ mixes, different slabs have been constructed during the laying phase. Then, the slabs have been tested at 50 °C according to the EN 12697-22. Moreover, the rutting resistance under severe conditions have also been assessed through a test at 60 °C. Indeed a test with extreme temperature has been found relevant as it would be possible to have HMA underlayers that could reach very high temperature in some south-European countries for instance.

Making a study with reclaimed asphalt, the behaviour of the binder and especially the mix of old and new binder are also important. In order to assess this parameters, a specific study of the binders in different conditions (in-situ, laboratory mix, aged, ..) was carried out. In this specific study, some classical tests (pen, R&B) have been performed but also rheological tests like DSR (dynamic shear rheometer).

Different coring campaigns were carried out during the tests at the ALT facility: before the beginning of the tests, after the fatigue tests and at the end of the low temperature tests as well. At each stage, cores have been taken in undisturbed areas and/or in wheel path, this in order to further analyse the effect of the load and temperature on the pavement characteristics.

Finally, a specific test in controlled conditions has been performed on big slabs taken in the ALT facility. While the tests in the ALT facility focused on fatigue testing at 15 °C and low temperature tests, it has been decided to investigate the mix behaviour at elevated temperatures. Hence, three large slabs were extracted from undisturbed areas and sent to DRI for testing in the Danish Asphalt Rut Tester (DART)

The DART device permitted to simulate a rolling load with side wander. As it is built into a conditioning cabinet, air temperature can be controlled from 25 °C to 60 °C. Moreover, the apparatus permitted to obtain a constant and controlled temperature gradient in the slab with 40 °C at the top of the pavement and 20 °C at the bottom of the pavement in our test case. Main data for the device are in brief:

- Stationary heavy vehicle simulator with linear travel 0-5 km/h (24'000 loads/day)
- Wheel load up to 65 kN (corresponding to 130 kN axle load)
- Random normally distributed wander (± 200 mm from centre travel)
- Full-size standard lorry tyre, single or dual wheel configurations
- Test sample 1200 mm by 1500 mm, thickness 100-250 mm
- Automatic rutting and macro texture measurements with precision laser profilometer

5.2 Results of tests carried out on the tested material of the ALT-sections

Concerning the tests in DART on big slabs, a standard testing has been conducted with 50 kN wheel load and 110'000 load applications. Using this standard testing, the results can then be compared with the results obtained on Danish Motorway pavements. After first tests according to the standard procedure, a further 44'000 loads were applied at an elevated temperature of 50 °C surface temperature / 40 °C bottom temperature, this in order to be sure to reach rutting and analyze the limits of the material as well. The permanent deformation developments for the three slabs are illustrated in the following figure:

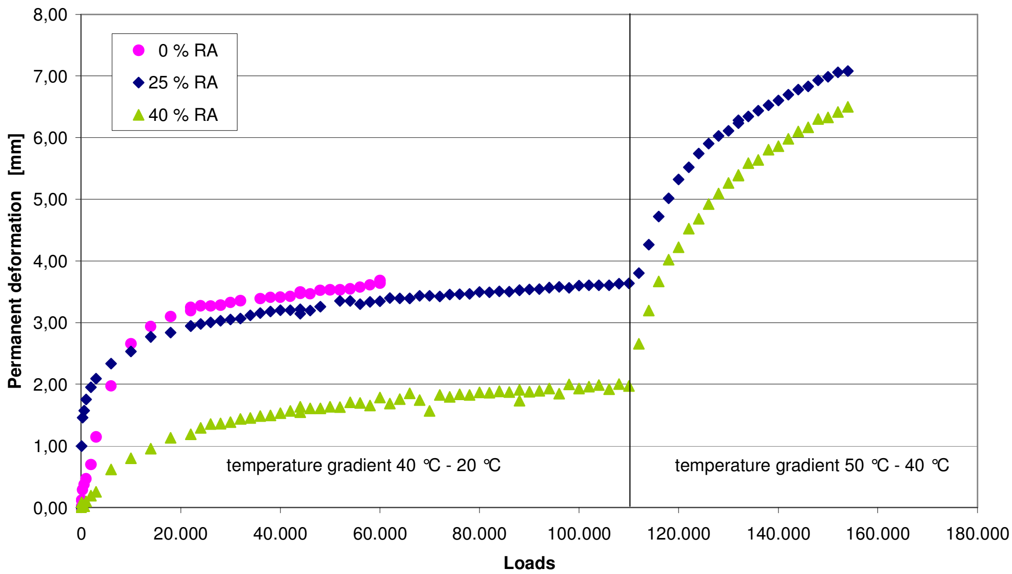

Figure 8: Rutting behaviour for the three tested slabs

As the deformation obtained during the first 20'000 loads will to some extent mainly depend on initial compaction under the wheel load, it cannot be concluded from these data that rutting of the slab with 40 % RA is much less pronounced than for the other two slabs. For a comparison of rutting behaviour of different slabs without this initial disturbance, the increase of rutting from 20'000 to 40'000 loads is calculated. For the different slabs we obtained a rutting increasing between 0.25 mm (25 % RA) and 0.32 mm (0 % RA). Comparing these results with the Danish standards on highways (between 0.5 and 5 mm), we conclude that rutting susceptibility is much better than for standard motorway pavements. Moreover, no significant difference between the different slabs can be determined. Concerning elevated temperature tests, the slab with 40 % RA had a slightly faster rutting development than the slab with 25 % RA, but not significant.

6. Conclusions

One of the innovations considered in the European NR2C-project consisted in designing high stiffness base layers with high percentages of reclaimed asphalt, while guaranteeing the long-term performance. Different mixes with different percentages of RA (0%, 25 % and 40 %) and with Belgian as well as Swiss materials were designed and optimized and their performance in relation to stiffness, fatigue cracking, water sensitivity and permanent deformation was determined and compared.

High performance mixtures were obtained with equivalent performance for mixes with RA than mixes without RA, provided that an optimization of the mix design was performed based on the analytical mix design study and on the results of the performance tests. Three designed mixtures were further tested in the ALT-testing facility of LAVOC. No failure was observed in these experiments and mixes with RA showed equivalent performance as mixes without RA. It was shown that the use of high percentage of reclaimed asphalt in underlayers has no negative effects on the laboratory mix performance. ALT, wheel tracking tests, tests in DART and also laboratory tests on cores and binders samples came to the same conclusion that no negative effect of a high percentage of RA could be identified so far.

However, it is important to keep in mind that such a conclusion cannot be extended to all the HMA mixes. Some parameters like the grading curve, recycling material and binder type play a key role in the final properties. Considering these elements, it is recommended to put a special emphasis on the characterisation of the reclaimed asphalt, on the mix design and on the laboratory tests, this in order to avoid further problems.

7. References

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