Asphalt mixture performance and testing

**Use of PmB's for road recycling: a case study in France highways**

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Abstract

Due to economic and environmental considerations, the use of Reclaimed Asphalt Pavement (RAP) is growing more and more in developed countries. In France, traditional percentage of RAP is around 20% with an increasing tendency. Depending on RAP characteristics and asphalt mix formulation, high RAP content formulation can present poor performance of the mix at low temperature/winter conditions. One challenge is to add the appropriate binder in order to maintain performance of the asphalt mix at low temperature. There are different approaches to recycling, in the present work, the impact of binder's nature is studied in the case of 50% RAP content mixtures. Four types of mixes have been studied, two with standard bitumen (35/50 and 50/70 grade) and two with polymer modified binders. All binders and mixes properties have been characterized at initial state and after ageing steps both in the lab and in field. Binder characterization included empirical testing such as penetration, Ring & Ball, FRAASS breaking point and rheological properties obtained with DSR and BBR. Then, those results are correlated to TSRST results obtained on asphalt mixes. This study demonstrates that simple consideration such as penetration, Ring & Ball and FRAASS are not sufficient to select the right solution with high RAP content mixes. It also shows the benefits of using PmB's instead of soft base binder to maintain a high level of performances.

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## 1. INTRODUCTION

Due to economic and environmental considerations, the use of Reclaimed Asphalt Pavement (RAP) is growing in developed countries. In France, the traditional percentage of RAP is around 20% with an increasing tendency. It is however critical still for both economic and environmental reasons to ensure that the durability of the road is preserved while increasing RAP content.
For a long time, the use of RAP was limited to sublayers. It is now extended to top layers which are usually made, at least on motorways and on other heavily trafficked roads, with Polymer Modified Bitumen (PMB). The addition of both environmental and performance related needs leads to new technical issues that can only be solved through a partnership approach. It is exactly the reason why a private motorway owner, a road building company and a bitumen supplier are actively working together in order to improve the formulation and the choice of PMB for motorway wearing courses with a high level of RAP.
Depending on one hand on traffic conditions and climate and on the other hand on the choice of materials used in order to achieve the required performance level, motorway wearing courses usually deteriorate either due to raveling issues or because of superficial thermal cracking. In order to delay these phenomena and reduce maintenance operations, nearly all motorway wearing courses in France are designed with high performance PMB. Integration of RAP including aged and consequently oxidized binder can lead to poor performance of the mix at low temperature i.e. in winter conditions. The challenge is to add the appropriate binder in order to maintain performance of the asphalt mix at low temperature and for that it is necessary to use a properly designed Polymer Modified Bitumen.

## 2. A72 CASE STUDY AND RESULTS TO DATE

### 2.1. Description of the case study

A72 motorway is a 55km-long motorway going, in the direction South to North, from Saint-Etienne in the center of France to Nervieux where it merges with A89 motorway going from Lyon to Clermont-Ferrand. It is located in an area of average-sized mountains and the climate combines both continental and mountain area characteristics leading to relatively severe winters. For motorway wearing courses in this type of area, the choice is usually made to use *Beton Bitumineux Semi Grenu* (BBSG) which is typical French Asphaltic Concrete (AC) type of material, as it is considered the most durable option [1]. It can be noted that in areas where climatic conditions are not so demanding, thin open asphalt layers are usually preferred in order to ensure the right level of texture and to optimize costs. Both types of wearing course do not deteriorate through the same mechanisms. If thin layers often fail due to raveling because of the lack or the decrease of binder cohesion; asphaltic concrete used in areas of severe winter condition fail mostly because of superficial thermal cracking resulting from the hardening of the binder with time. In both cases, and in order to slow down the degradation effect and consequently reduce maintenance costs, polymer modified bitumen is systematically used on motorways. In the case described here, the study is focused on the evaluation of low temperature performance of AC mixes containing high percentage of RAP.

The study is realized essentially on samples taken on a section of A72 Motorway realized in October 2016. The purpose of the roadworks is to replace the wearing course originally made of BBSG 0/10 with Normal Paving Grade (NPG) bitumen with another BBSG 0/10 containing 50% of RAP. The reference formulation chosen by the road owner ASF for the site is a BBSG 0/10 class 3 made with 50% RAP and the fresh binder added is a PMB 45/80-50 referred as PMB1 in this paper. In order to assess the interest to use a specially designed binder, a trial section is realised with exactly the same formulation but using a binder formulated for such asphalt mixes with high level of RAP referred to as PMB2. The level of modification of PMB2 is higher than PMB1 in order to take into consideration the dilution of the polymer content during the mixing stage.
The asphalt mix formulation is described in table 1.

**Table 1. Asphalt Mix formulation**

| Components | Proportion |
|---|---|
| 0/4 | 16.3% |
| 6/10 | 30.2% |
| RAP 0/14<br>*(Included binder)* | 50%<br>*(2.7%)* |
| Added Binder | 2.5% |

In order to widen the scope of the study and to fully quantify the benefit of using PMB, a second part of the study is carried out on two formulations made from NPG bitumen. Indeed, it seems interesting to compare the results obtained on formulations applied on A72 with two other formulations: one formulation without any RAP and made with NPG 35/50 and one formulation with 50% RAP and made with 50/70. These formulations were not applied on the motorway and all the results relative to these formulations are from laboratory studies.

**Figure 1: A72 trial section realisation**

## 2.2. Technical Program

The study is divided into three main parts:

- Characterisation of the fresh binders and of the binders after short term aging simulated using the Rolling Thin Film Oven Test (RTFOT)
- Characterisation of the asphalt mixes just after manufacturing (referred as "t0" in this paper) and characterisation of the binders recovered from asphalt mixes at t0. Samples considered are samples taken at the asphalt plant for both formulations using PMB and samples manufactured in laboratory for both formulations using NPG
- Characterisation of the asphalt mixes and respective recovered binders after simulation of aging in laboratory using the protocol designed by the RILEM TC-ATB Task Group [2]

In this study, the binder recovery is carried out using a protocol adapted by TOTAL based on toluene extraction and using Strassentest type of equipment.

The focus of the study is on low temperature cracking resistance. The reference test on asphalt mix is based on Thermal Stress Restained Specimen Test (TSRST) [3] as this test predicts relatively well low temperature field performance [4,5,6,7]. The characterisation of the binders is done through empirical tests such as Penetration, Softening Point and Fraass but also rheological tests using Bending Beam Rheometer (BBR) [8]. So, as far as low temperature performance is concerned, two tests are used, the Fraass test which is still the most commonly used test in France to assess binder low temperature performance and which is often used by road owners in their tender documents but also BBR which seems far better at predicting binder performance [6].

When assessing performance of binder in asphalt mix using large quantity of RAP, it is absolutely necessary to consider remobilisation aspects. Indeed, the process of binder recovery based on solvent extraction leads to a full extraction of the recomposed binder coming from both old and new bitumen, but it artificially homogenises the binder which might then not be representative of the binder as it is in the road. There is no standardised test to assess remobilisation level, however Eurovia has developed a method based on progressive binder recovery in order to separate layers of binder around aggregates [9]. Binders are then analysed using Infrared Spectroscopy in order to determine a CO index representative of the quantity of carbonyl functions which is an indicator of the binder oxidation. Homogeneity of the binder is then evaluated looking at the evolution of the CO index of the binder during the different stages of the progressive recovery process.

The details of the tests carried out on the binders, either on original binder and on binder after short term aging (part 1) or on recovered binders (part 2) are described in table 2, whereas the details of the tests carried out on asphalt mixes are described in table 3.

**Table 2. Technical Program on binders**

| Binders | Conditions considered | Tests |
|---|---|---|
| PMB1<br>PMB2<br>NPG 35/50<br>NPG 50/70 | Fresh binder<br>After Short Term Aging RTFOT (EN 12607-1)<br>Recovered binders from Asphalt mixes | Penetration (EN1426)<br>Softening Point (EN 1427)<br>Fraass Breaking Point (EN 12593)<br>BBR (EN 14771) |

**Table 3. Technical Program on asphalt mixes and recovered binders**

| Asphalt mix | Origin of the samples | Characterisation t0 | Characterisation after RILEM aging Protocol |
|---|---|---|---|
| BBSG10 50% RAP + PMB1<br>BBSG10 50% RAP + PMB2 | Asphalt plant | Compaction in lab of loose asphalt<br>TSRST on compacted asphalt<br>Remobilization Testing<br>Binder recovery | Compaction in lab<br>TSRST on compacted asphalt<br><br>Binder recovery |
| BBSG10 0% RAP + NPG35/50<br>BBSG10 50% RAP + NPG50/70 | Lab mix | Mixing and compaction<br>TSRST<br>Binder Recovery | Mixing and compaction<br>TSRST<br>Binder Recovery |

### 2.3. Results

The binder recovered from the RAP is quantified and analysed and the results are shown in table 4. The recovered binder is particularly hard resulting from its oxidation during its lifetime on the road.

**Table 4. Binder content and binder analysis of recovered binder from RAP**

| Binder content (%) | Penetration (1/10mm) EN 1426 | Softening Point (°C) EN 1427 |
|---|---|---|
| 5.8 | 11 | 71 |

All the results obtained on fresh binders are shown in table 5. From these results and specifically regarding low temperature performances it can be seen that the Fraass test does not discriminate the binders very well. Looking at BBR results it can be seen that PMB2 shows better behaviour than PMB1 which is just slightly better than NPG 50/70. It must be reminded that BBR is a better indicator than Fraass to predict low temperature behaviour in the road. [6]

**Table 5. Characterisation of the fresh binders used in the study**

| Test | Unit | Standard | PMB1 | PMB2 | NPG 35/50 | NPG 50/70 |
|---|---|---|---|---|---|---|
| Penetration | 1/10mm | EN 1426 | 57 | 64 | 39 | 58 |
| Softening Point | °C | EN 1427 | 56.2 | 77.2 | 52.6 | 49.4 |
| Fraass Breaking Point | °C | EN 12593 | -16 | -15 | -13 | -16 |
| BBR Ts=300 MPa | °C | EN 14771 | -18.5 | -21.2 | -15.2 | -17.4 |
| BBR Tm=0.3 | °C | EN 14771 | -18.9 | -21.3 | -16.6 | -18.5 |

All these binders are conditioned using RTFO method in order to simulate oxidation incurring during asphalt mix stage. The same characterisations are carried out after this short-term aging phase and shown in table 6. If we focus on low temperature behaviour, it can be seen that all binders have a slight decrease in performance after-short term aging but the decrease is lower for both PMB than for both NPG. This trend has already been shown in previous studies. [7]

**Table 6. Characterisation of the binders after short-term aging using RTFOT**

| Test | Unit | Standard | PMB1 | PMB2 | NPG 35/50 | NPG 50/70 |
|---|---|---|---|---|---|---|
| Penetration | 1/10mm | EN 1426 | 34 | 48 | 26 | 34 |
| Softening Point | °C | EN 1427 | 60.2 | 74.4 | 59 | 59 |
| Fraass Breaking Point | °C | EN 12593 | -17 | -16 | -13 | -14 |
| BBR Ts=300 MPa | °C | EN 14771 | -16.8 | -20.7 | -15.4 | -16.5 |
| BBR Tm=0.3 | °C | EN 14771 | -18.2 | -20.8 | -14.5 | -17.2 |

In order to evaluate the performance at low temperature of the asphalt mixes, asphalt mix slabs are compacted using loose asphalt sampled in the asphalt plant for both formulations using polymer modified bitumen and manufactured in laboratory for both formulations using NPG. These slabs are then cored in order to make specimens used for TSRST. Results of these different configurations are shown in table 7, each single result being the average of at least 3 individual measurements. From these results it can be seen that the low temperature performance of the mix containing RAP and pure bitumen is not as good as the one of the same mix made without RAP. So clearly the presence of RAP has a negative effect on low temperature behaviour. The use of polymer modified bitumen can help to reduce this negative impact and even to restore properties equivalent to a mix without RAP as the result of the mix using 50% of RAP and 50% of PMB2 is equivalent to the result of the mix with NPG 35/50 without any RAP.

**Table 7. TSRST results on asphalt mix after manufacturing**

| Recomposed binder of the Asphalt mix | Manufacturing | Void content (%) | TSRST Cracking Stress (MPa) | TSRST Cracking Temperature (°C) |
|---|---|---|---|---|
| 50% PMB1 + 50% RAP Binder | Plant | 3.6 | 4.3 | -22.0 |
| 50% PMB2 + 50% RAP Binder | Plant | 3.0 | 4.6 | -24.2 |
| 50% NPG 50/70 +50% RAP Binder | Lab | 4.4 | 3.8 | -20.9 |
| NPG 35/50 | Lab | 5.1 | 3.9 | -24.7 |

The same loose asphalt mixes are also conditioned in ovens to be aged following RILEM protocol and then again compacted and cored to make specimens for TSRST. It is important to look at low temperature performance after aging as it is known that performance decreases in time with oxidation. Results are presented on table 8.

Firstly, it can be noted that the variations observed between tests after mixing and tests after long-term aging seem consistent, showing for all mixes an increase of Cracking Temperature. Both asphalt mixes made from PMB show very good TSRST results after aging, both being lower than -19°C. Their Cracking Temperatures, respectively -19.7°C and -21.9°C are significantly better than the results measured with exactly the same formulation and the same RAP content but made with NPG 50/70. Formulation with PMB2 and RAP shows the best result amongst all.

It is also interesting to compare results obtained with formulations using PMB and binder from RAP with the formulation with NPG 35/50 and without any RAP. Formulation without RAP shows performance equivalent to the formulation with 50% and with PMB1, respectively -19.4°C and -19.7°C and shows performance significantly worse than the formulation with RAP and with PMB2.

The measurement of the Cracking Stress is also interesting to analyse. Both formulations using PMB show higher cracking stresses than the ones with standard bitumen respectively with or without RAP. Performance of the formulation using PMB2 is again better than the other ones.

As a conclusion it can be said that the low temperature performance of the formulation containing PMB2 and RAP is the best one, better than formulation with RAP and PMB1 which shows a performance close to a formulation without RAP and made with NPG 35/50. The worst performing formulation is the one made with RAP and with NPG.

**Table 8. TSRST results on asphalt mix after simulation of long-term aging with RILEM Protocol**

| Recomposed binder of the Asphalt mix | Manufacturing | Void content (%) | TSRST Cracking Stress (MPa) | TSRST Cracking Temperature (°C) |
|---|---|---|---|---|
| 50% PMB1 + 50% RAP Binder | Plant | 4.6 | 4.0 | -19.7 |
| 50% PMB2 + 50% RAP Binder | Plant | 3.1 | 4.6 | -21.9 |
| 50% NPG 50/70 +50% RAP Binder | Lab | 3.9 | 3.9 | -16.9 |
| NPG 35/50 | Lab | 5.9 | 3.7 | -19.4 |

Binders are recovered from the different asphalt mixes tested and are characterised. Table 9 shows the results obtained on the binders extracted just after the mixing stage and Table 10 shows the results on binders extracted after long term aging in laboratory using RILEM protocol. Focusing again on low temperature performance, it can be noticed first of all that the results obtained using the BBR method rank the recovered binders in the same order that the TSRST test on asphalt. This confirms that BBR is probably a better tool than Fraass to predict low temperature performance. It can also be seen that the binder containing PMB2 shows the best performance both before and after aging. Still considering BBR results, it is confirmed that the binder recovered from a mix containing 50% RAP and prepared using PMB1 performs the same way at low temperature than the recovered pure NPG 35/50. More generally, looking at Penetration and Softening Point results, it can be noticed that the different recovered binders seem relatively similar whereas their performance at low temperature shows very different behaviours. This confirms that Penetration and Softening point alone are not sufficient for the characterisation of recovered binders.

**Table 9. Results on binders recovered from Asphalt mixes after mixing**

| Test | Unit | Standard | 50% PMB1 + 50% Binder from RAP | 50% PMB2 + 50% Binder from RAP | NPG 35/50 | 50% RAP + 50% NPG 50/70 |
|---|---|---|---|---|---|---|
| Penetration | 1/10mm | EN 1426 | 18 | 22 | 23 | 18 |
| Softening Point | °C | EN 1427 | 65.6 | 64 | 63.6 | 68 |
| Fraass Breaking Point | °C | EN 12593 | -5 | -15 | 3 | 5 |
| BBR Ts=300 MPa | °C | EN 14771 | -13.9 | -17.3 | -14.2 | -11.9 |
| BBR Tm=0.3 | °C | EN 14771 | -13.2 | -17.6 | -12.7 | -10.5 |

**Table 10. Results on binders recovered from Asphalt mixes after RILEM long-term aging**

| Test | Unit | Standard | 50% PMB1 + 50% Binder from RAP | 50% PMB2 + 50% Binder from RAP | NPG 35/50 | 50% NPG 50/70+50% RAP Binder |
|---|---|---|---|---|---|---|
| Penetration | 1/10mm | EN 1426 | 11 | 13 | 18 | 14 |
| Softening Point | °C | EN 1427 | 70.8 | 72.8 | 69.6 | 73.6 |
| Fraass Breaking Point | °C | EN 12593 | -2 | -2 | 5 | 7 |
| BBR Ts=300 MPa | °C | EN 14771 | -13.2 | -15.1 | -13.1 | -11.4 |
| BBR Tm=0.3 | °C | EN 14771 | -10.1 | -12.1 | -9.5 | -6.9 |

All the results shown on tables 9 and 10 are obtained on binders recovered using solvent extraction method. One should keep in mind that by recovering binders using such methods, the homogeneity of the resulting binders is perfect as the solvent helps to mix the binder from the RAP with the added binder. Consequently, it is difficult to know if the binder tested is actually representative of the binder which was in the asphalt mix, as the latter might not be fully homogeneous. In order to answer that point, the research Centre of Eurovia has developed a method to assess the homogeneity of the binder in an asphalt mix using successive leaching steps in order to separate several layers of binders around the aggregates [9]. Infra-Red spectroscopy analysis is then used to characterise each layer of binder. Using Infra-Red spectrums it is possible to calculate a CO Index which is an indicator of the quantity of carbonyl functions which characterises the oxidation of the binder. A reference CO Index (ICOref) is determined using the first few solutions resulting from the successive leaching operations. Homogeneity of the binder is then evaluated using the ratio of the average of the last ICOi divided by the ICOref. (Figure 2). The binder from RAP is more oxidised than the added binder. Consequently, if all the different solutions show comparable ICO, it shows that the binder is fully homogenised.

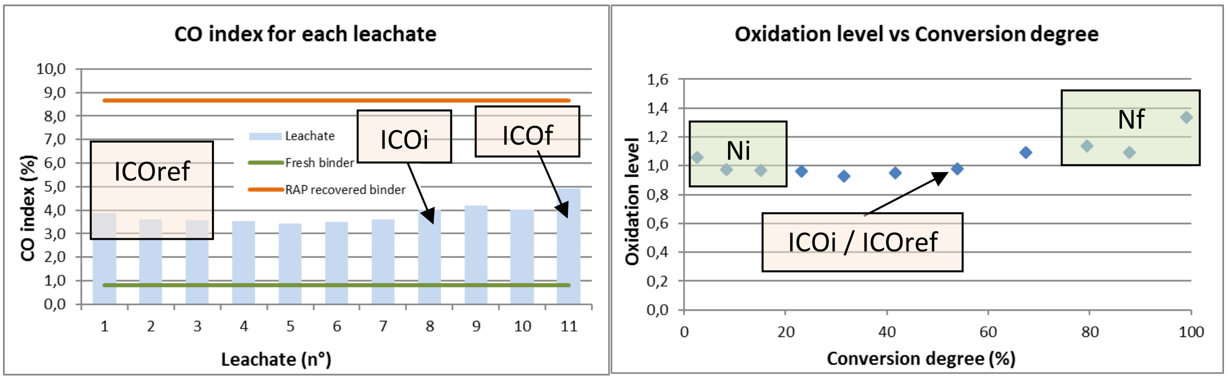


**Figure 2: Method developed by Eurovia to characterise homogeneity of the binder**

Results on the asphalt mixes using respectively PMB1 + RAP and PMB2 + RAP are shown in figures 3 and 4. Considering the precision of the methodology, it can be concluded that for both mixes, the level of CO functions is similar in all the different solutions resulting from the successive extractions. Consequently, it can be concluded that the binders resulting from the recombination of the PMB and of the aged binder from the RAP are homogeneous in the asphalt mixes and that the results obtained in tables 9 and 10 on recovered binders are representative of the binders used on the A72 motorway.

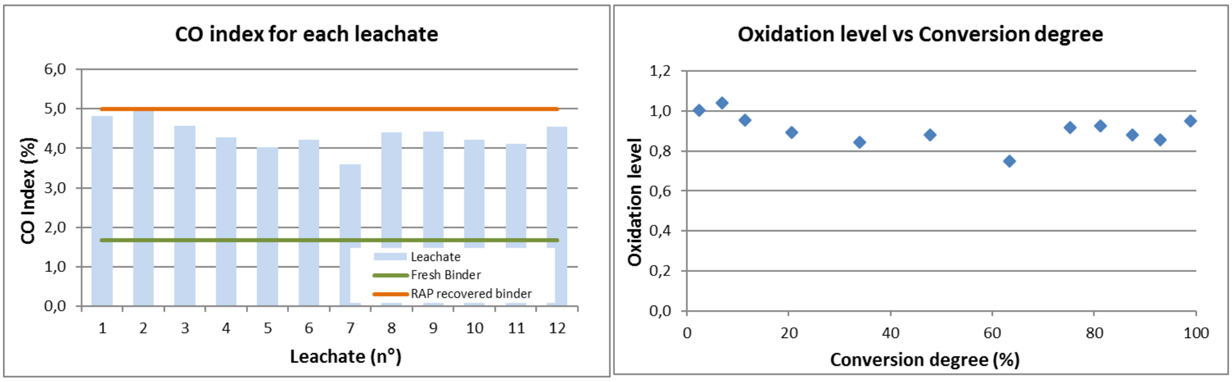


**Figure 3: Verification of the homogeneity of the binder recomposed from RAP and PMB1**

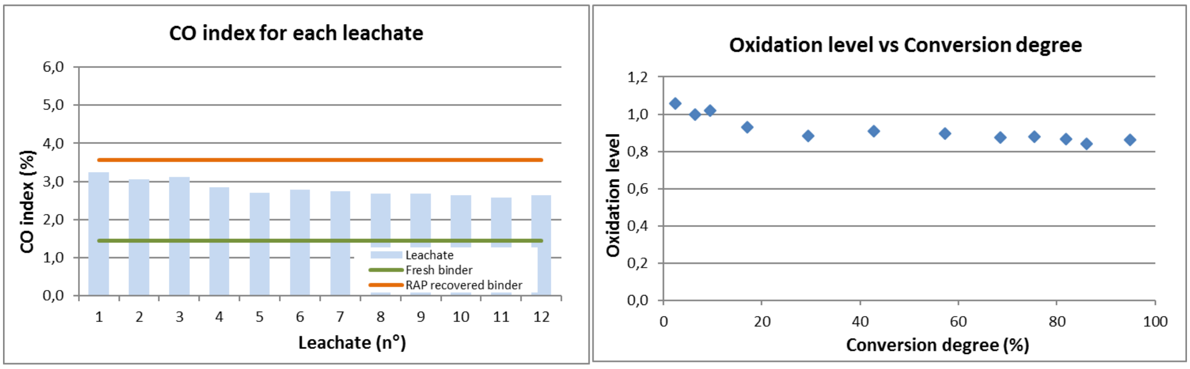


**Figure 4: Verification of the homogeneity of the binder recomposed from RAP and PMB2**

### 2.4. Conclusion

This collaborative study shows that the use of high quality PMB allows to successfully design asphalt mixes using high level of RAP content and still showing very good low temperature performances. Asphalt mixes prepared with 50% of RAP and polymer modified bitumen can lead to performance equal or even higher than mixes prepared with NPG and without RAP. It can also be noted that in this study, all results of BBR on fresh binders, on binders after RTFOT, on recovered binders are very consistent providing the same ranking between the different studied solutions. BBR results are also very consistent with results obtained on the asphalt mixes using TSRST method. This confirms the interest in using BBR rather than other tests such as Fraass to characterise binders at low temperatures. This study will be followed-up and coring is already planned and will be carried out in the second half of 2019. A second set of cores is also planned for 2022. It will be possible to check if the results anticipated in the lab using long-term aging method are consistent with real field observations.

## 3. ACKNOWLEDGEMENTS

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# Annex

# 1. FOLLOW-UP OF A72 CASE STUDY AFTER 3 YEARS

In order to assess and compare the performances of the two materials respectively used for the two sections described in part 2 of the original paper, it was planned to organise some coring on both reference and trial sections and to carry out some analyses. The coring is realised in November 2019 so 3 years after the laying of the asphalt on the site and the results are detailed in this annex.

## 1.1. Selection of the coring zones

To help choose the best areas for coring, a mapping of the degradations is organised by ASF using high speed on-board degradation recording devices. The graphical representation is shown in Figure 1. No degradations are observed on the trial section and only very limited and localised degradations can be observed on the reference section. These degradations are localised on a bridge and seem to be directly linked to the infrastructures and thus it is decided not to core in that area. For practical reasons it is also decided to core the sections relatively close to the joint between the two parts so safety aspects in relation to motorway traffic can be managed more efficiently. For both sections the right lane is cored close to the middle axis of the section. 3 cores of 300 mm diameter are sampled in each of the 2 sections.

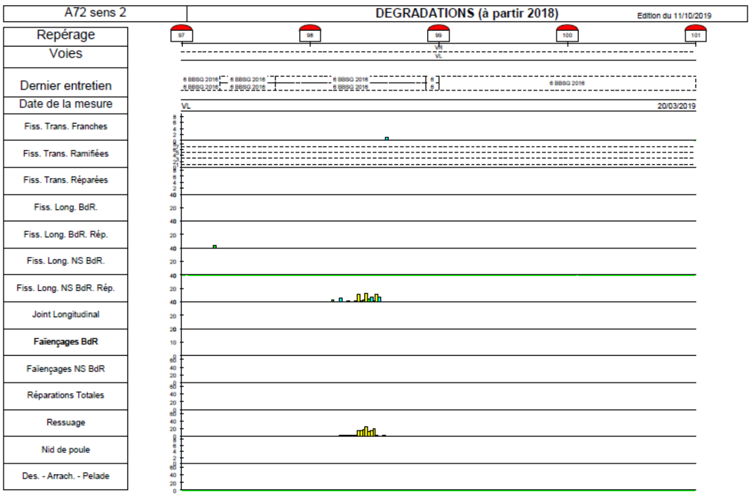


**Figure 1: Degradations observed on reference and trial sections**

## 1.2. Testing program

Table 1 below shows the test chosen, taking into consideration the focus of the study on Low Temperature Cracking resistance and the tests carried out originally on the asphalt sampled in the asphalt plant.

**Table 1. Testing Program**

| Material considered | Origin of the samples | Characterisation |
|---|---|---|
| Asphalt mix BBSG10 50% RAP+PMB1 | Cores from reference section | TSRST - Binder recovery |
| Asphalt mix BBSG10 50% RAP+PMB2 | Cores from reference section | TSRST - Binder recovery |
| Binder 50% RAP+PMB1 | Recovered from cores | Penetration-Softening Point-BBR |
| Binder 50% RAP+PMB2 | Recovered from cores | Penetration-Softening Point-BBR |

## 1.3. Results

Specimen of 50 mm diameter are extracted from the original cores (300 mm of diameter) in order to carry out TSRST on the wearing courses only. For each section, the results given below are the average of the results obtained on 3 replicas of 50 mm diameter.

Results are shown in Table 2. It is observed that the Cracking Temperature is similar for both sections and show very good Low Temperature Performance in both cases. The trial section shows a slightly better performance than the reference section. The results obtained here after 3 years are also very similar to the results obtained just after mixing (T0). In fact, the results after 3 years are slightly better which can be explained by the difference of heating protocol between the two sets of tests.

**Table 2. TSRST results on asphalt mix after 3 years**

| Recomposed binder of the Asphalt mix | Void content (%) | TSRST Cracking Stress (MPa) | TSRST Cracking Temperature (°C) |
|---|---|---|---|
| 50% PMB1 + 50% RAP Binder | 5.7 | 2.9 | -23.7 |
| 50%PMB2+50%RAP Binder | 5.8 | 2.6 | -25.5 |

Binder is recovered from the wearing course slice cut from the cores and analysed according to the test program. Penetration, Softening point and BBR tests are carried out on both binders and the results are shown in Table 3. Results for penetration and softening point show little evolution compared to the results obtained just after mixing (T0). Performances in BBR are shown in Table 3 and are compared in figure 2 with results obtained on the binder recovered after mixing and on the binder recovered after RILEM long-term ageing (see Tables 9 and 10 of original paper). Some limited evolution is observed compared to results at T0. Temperature corresponding to Ts=300 MPa is close after 3 years to the one measured after RILEM ageing, whereas for the Tm=0.3 criterion the results after 3 years are still better than the ones measured after RILEM ageing.

**Table 3. Binder results on recovered binder after 3 years**

| Test | Unit | Standard | 50% PMB1 + 50% Binder form RAP | 50% PMB2 + 50% Binder form RAP |
|---|---|---|---|---|
| Penetration | 1/10mm | EN 1426 | 20 | 21 |
| Softening Point | °C | EN 1427 | 63.4 | 66.8 |
| BBR Ts=300 Pa | °C | EN 14771 | -14.3 | -15.4 |
| BBR Tm=0.3 | °C | EN 14771 | -13.2 | -13.5 |

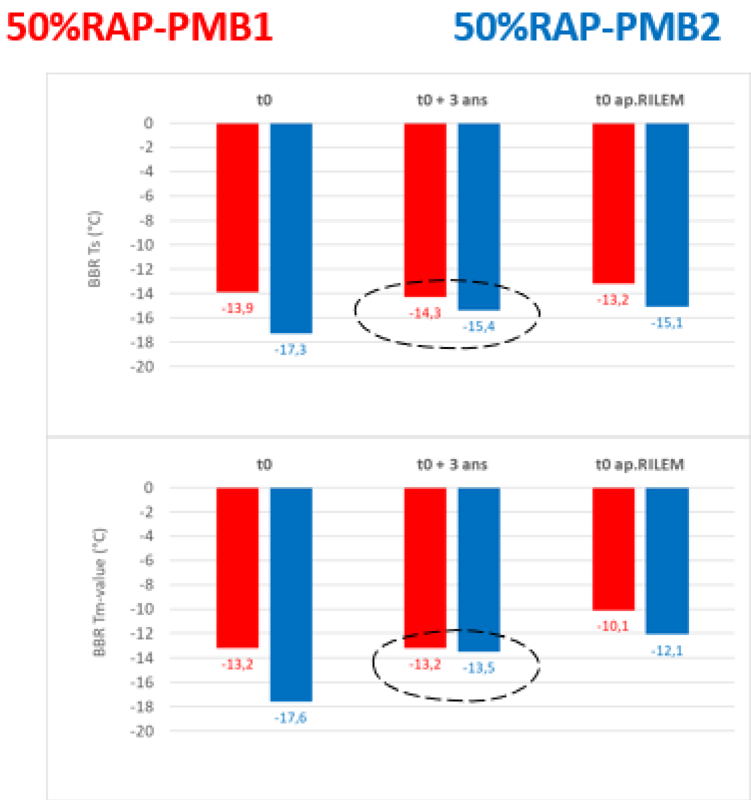


**Figure 2: Comparative results on Low Temperature performance (BBR) at T0, after RILEM ageing and after 3 years on the road**

## 2. CONCLUSION

As originally planned, cores are taken after 3 years on both sections. At this stage Low Temperature Performances measured on asphalt mixes and on recovered binders are still very close to original performances. Both sections do not show any premature sign of degradation. Next set of cores is planned in 2022.