Sustainability & Environment

BioRePavation - Innovation In Bio-Recycling

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Abstract

The main scientific and technical objectives of the BioRePavation project have been to prove that alternative binders can be used to recycle asphaltic pavement with the same level of performance as conventional solutions with petroleum bitumen. To do so, the consortium proposed to build a demonstration where three innovative pavement solutions using bio-materials were tested using an accelerated pavement testing facility (IFSTTAR fatigue carousel): - A bio-based additive from pine chemistry designed to Increase RA content to 70%, even 100% in theory - A Bio-based additive designed to increase compatibility between fresh bitumen and RA: Epoxidized Methyl Soyate - A Bio-bitumen designed for full replacement of fresh bitumen The survey of performance was performed by both measuring the traffic level needed for the pavement solution to reach a distress mechanism and investigating the binder physicochemical evolution using an innovative non-destructive method. BioRePavation also assessed the environmental impacts of the combined use of bio-binders and high-content of RA in asphalt mixes. Special attention was given to airborne emissions that were directly measured in the laboratory. Obtained data were used to perform a risk assessment, as well as a Life Cycle Assessment (LCA) for the aforementioned BioRePavation technologies. Finally, the proof of concept was demonstrated: the innovative pavement mixes assessed in the BioRePavation international project behave better than a conventional reference mix. They now provide durable solutions, assessed by a full scale accelerated test and an environmental analysis, to build roads using high rate recycling and involving biomaterials as additive or alternative to bitumen.

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INTRODUCTION

The infrastructure construction industry is a bulk consumer of extracted raw materials. Due to geological and societal constraints, the supply of these materials is decreasing and their prices are on the rise. The limited availability of certain mineral aggregates and crude oil that are fit for the production of bitumen has become a major concern to the industry with the effect that recycling and reuse have become well-established practices in many countries. Increasing RA content is providing high environmental benefits since it could reduce long-haule transportation of aggregate and it generally allows reduction of the need for virgin petroleum-based binder in mixes [1][2][3][4]. One of the key technical issues is to take advantages of the remaining bitumen from RA, even if its physical state is too brittle and stiff to meet virgin binder criteria [5][6]. The problematic is then to find appropriate new binders and/or additives, able to re-activate the aged binder to achieve desirable viscoelastic behaviour.

Another option considered by asphalt technologists to reduce the dependence from the oil industry is the introduction of alternative binders and/or other surrogate such as bio-based materials.

In order to reply to questions on the use of innovative alternative bio-based materials in recycling of RA, a full-scale demonstrator has been built for evaluation under real traffic conditions at the IFSTTAR Accelerated Pavement Testing facility (APT). The main innovation in this project is the use of bio-based materials obtained from renewable bio-mass and used as recycling agents to design durable asphalt mixtures with 50% RAP.

The aim of this study was to demonstrate the possibility to implementing the bio-recycled asphalt mixtures on actual road networks. Three proprietary bio-based materials, were used to perform tailored laboratory mix design and the validation was undertaken in a real scale experiment conducted at the accelerated pavement testing facilities at IFSTTAR. This paper will illustrate the outcomes of the monitoring of the four pavement sections, one was a control pavement structure with EME2 and the three other with mixes made with 50 % RA and bio-based materials, were subjected to a year-long testing aimed at accelerating rutting and fatigue cracking of the materials.

Additionally the different pavement sections were cored and sampled with a new innovative non-destructive micro sampling technique combined with extraction and binder evaluation using Dynamic Shear Rheometer (DSR).

Airborne emissions were directly measured in the laboratory as well.

1. MATERIALS AND METHODS

The aim of the project was to maximise the use of RA with bio-based materials. For this purpose, three mixes were designed incorporating 50% RA content, in association with three different and complementary innovative bio-based materials [7]:

- Mix1: designed with a bio-based rejuvenator, SYLVAROAD™ RP1000, a performance Additive, from Kraton Chemical used to treat the RAP. It is specifically designed to increase RA content up to 100 % or to reuse very hard, low quality RA [8][9].
- Mix2: designed with a bio-binder, Biophalt® [10], from Eiffage Infrastructures, for total replacement of bituminous binder in recycling techniques.
- Mix3: designed with a bio-based additive from Iowa State University, an Epoxidized Soybean Soyate (EMS) aimed to compatibilise virgin binder and aged binder from RA.

Aggregate grading curve and binder content were chosen using aggregate packing optimisation concepts (GB5®) in order to maximize mix density and particle interlock [11][12][13]. The properties of these three mixes (mix 1, mix2 and mix3) were compared with an EME2 which is the reference High Modulus Asphalt in the world. The choice of using 20% RAP in this mix is because 20% is he average recycling rate in Europe.. All the mixes are made with the same aggregates, from La Noubleau quarry.

Figure 1 presents the final grading curves of the different materials manufactured in plant, in comparison with the target theoretical grading curve of the GB5® material. The three innovative materials present very similar grading curves to the one targeted, whereas the reference one for EME2 presents a finer gradation. These results show that it is possible to obtain this particular grading curve at asphalt plant production. Table 1 presents the final compositions of the mixes produced in plant for the full-scale test.

Fatigue and complex modulus properties of the mixes produced in plant are given in Table 2. All mixes exhibit high modulus, superior to the European criteria for materials commonly used in base or binder layers. The fatigue resistances of the tested mixes, measured in lab, was lower than the reference mix.

Before construction, laboratory rutting tests were performed on mixes produced in lab following the European method (EN 12697-22 Large size device, French wheel tracking test) and US method (flow number test). Results are presented in Table 3.

All three innovative materials met the European and US specifications for resistance to rutting. According to the European method, the results are similar for the three mixes, taking into account the repeatability of the tests.

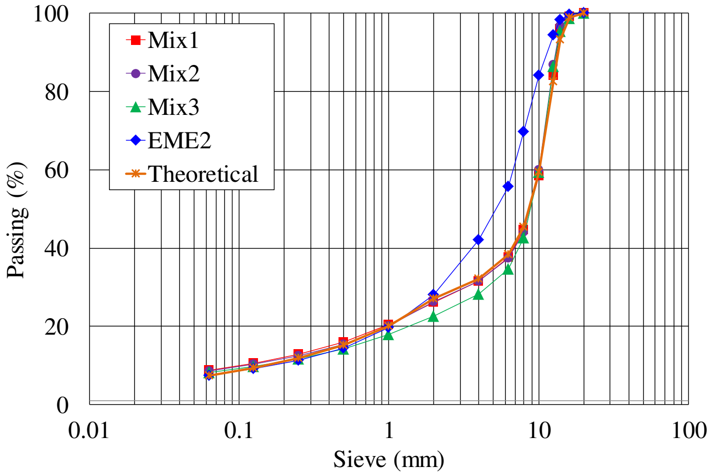


Figure 1: GB5® and EME 50% RA mixtures' gradation

Table 1. Binder content and size of aggregates of mixes produced in plant (control measurements)

Mixes	Mix1	Mix2	Mix3	Theoretical GB5 type	EME2
Binder content	4.49%	4.44%	4.36%	4.5%	5.26%
0/2 mm	17.3 %	17.7%	14.4%	19.6%	20.5%
2/4 mm	5.4%	5.3%	5.7%	5.1%	14.2%
4/6 mm	6.1%	5.9%	6.5%	6.2%	13.7%
6/10 mm	20.9%	22.6%	24.7%	21.0%	28.3%
10/14 mm	37.6%	36.8%	35.9%	33.9%	14.2%
14/20 mm	4.0%	3.2%	4.7%	6.8%	1.7%
Filler	8.8 %	8.6 %	8.1 %	7.4%	7.4 %

Table 2. Mechanical characteristics of the plant manufactured mix (compacted in lab)

	Void (%) from in-situ measurement	Stiffness parameters (15°C and 10Hz) [14]		Fatigue parameters (10 °C and 25 Hz) [15]	
		$|E^*|$ (MPa)	φ(°)	ε_6 (µstrain)	b
EME2	4.3	16770	10.3	126	-0.178
Mix1	2.9	14540	15.8	115	-0.190
Mix2	3.3	16200	16.7	100	-0.176
Mix3	4.5	16360	12.2	109	-0.156

Table 3. Results of laboratory tests for resistance to rutting

Mixes	Rut depth EU method NF EN 12697-22+A1 30 000 cycles at 60°C Rut Depth (%)	Rutting resistance (flow number) At 7% air void, T=54°C AASHTO TP-79 (cycles)
Requirements for a high modulus Mix	**< 7.5%**	Requirement medium traffic level **>190**
Requirements for a GB4 Asphalt base course material	**< 10%**	
Mix 1	5.6% (void content = 4.4%)	609
Mix 2	4.3% (void content = 3.5%)	578
Mix 3	3.7% (void content = 5.5%)	668
EME2	3.1 %	863

	(void content = 4.8%)	

2. ACCELERATED PAVEMENT TESTING

The fatigue carrousel of IFSTTAR is an outdoor road traffic simulator designed to study the behaviour of real scale pavements under accelerated heavy traffic. The fatigue carrousel has a diameter of 40 meters and four loading arms, which can each carry loads up to thirteen tons, at a maximum loading speed of 100 km/h (Figure 2). Two months of testing can represent up to 20 years of heavy traffic undergone by a moderate traffic pavement (150 heavy trucks/day). During loading, a lateral wandering of the loads can be applied to simulate the lateral distribution of loads of real traffic [16][17][18].

Figure 2: The IFSTTAR accelerated pavement testing facility

Four different structures, corresponding to materials described above, Mix1, Mix2, Mix3 and EME2, were tested simultaneously. Due to construction constraints, it was decided to have the same asphalt layer thickness, equal to 9 cm, for all materials. For each pavement structure, the design life was calculated at a risk of 50% and the associated risk after 1 million cycles. The results are displayed in Table 4. Initial design life calculation for the four pavement structures. The expected design life at a risk of 50 % was between 300 000 and 900 000 cycles with Mix2 structure having the shortest design life and mix1 and EME the longest design life.

Table 4: Initial design life calculation for the four pavement structures

	EME	Mix1	Mix2	Mix3
Asphalt layer thickness	9 cm			
Subgrade	80 Mpa			
Risk at 10^6 cycles	58 %	56 %	96 %	77 %
Life time at 50 %	$8.8\ 10^5$	$8.9\ 10^5$	$2.7\ 10^5$	$5.8\ 10^5$

The tested pavement structures are presented on Figure 3. The real thicknesses of the layers were measured at each phase of the pavement construction by means of topographical survey as well as measurements on core specimens (Figure 4). The real thickness of the asphalt layer was slightly lower than expected for Mix1 and higher for the reference mix EME2.

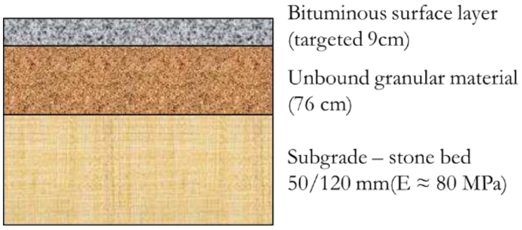
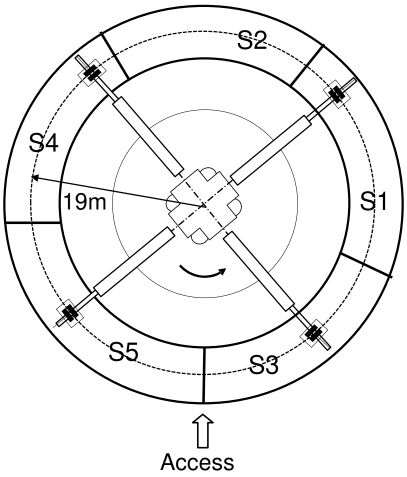


Figure 3: Tested pavement structures

The subgrade was made up with a stone bed (50/120 mm), and an unbound granular (UGM) subbase, consisting of three layers with a total thickness of 76 cm. The bearing capacity of the subgrade was measured at different positions on each structure by means of dynamic plate load test (NF P94-117-2), which gave values between 63 and 86 MPa for the stone bed, and between 103 and 111 MPa on top of the UGM layers. The reference section was approximately 30 m long, and the other sections had a length of 22 m, and all the sections were 4.5 m wide. The inner part of the test track was used for the rutting evaluation and the outer part was used for the fatigue evaluation.

The bituminous mixes were produced and the pavements were built on the 30th and 31st of May 2017 by Eiffage Infrastructures.



Structures	Bituminous mixes	Averaged measured Thickness
S1	Mix1	86 mm
S2	Mix2	95 mm
S3	Mix3	91 mm
S4	Not included in this study	-
S5	Ref - EME2	102 mm

Subgrade :
Stone bed 50/120mm
+ 76 cm of UGM

Figure 4: Layout of the five tested structures on the APT facility

2.1. Mechanical investigation

The full-scale experiment was realised in two phases:

- The first phase was performed between July and September 2017, to evaluate rutting behaviour under a 65 kN dual wheel load.
- The second phase was performed between November 2017 and March 2018, to evaluate the fatigue resistance of the structures, also under 65 kN load. Right before the end of this phase, after the application of 1 million load cycles, no tangible surface damage was observed on the four test sections. Therefore, it was decided to continue the experiment, and apply 400 000 additional load cycles, with a higher load (75 kN).

The loading conditions applied during the test are summarised in Table 5. With axle load equivalency the last loading with 75 kN had a higher agressivity than the 65 kN loading. Assuming a 4-power law, this agressivity is equal to (75/65)4 = 1.77, meaning that 400 000 cycles of 75 kN loading is equivalent to 709 000 cycles of 65 kN.

During the rutting test, loads were applied only when the pavement surface temperature exceeded 30°C. The pavement temperatures varied between 30 °C and 40 °C, with some short periods with higher temperatures, especially at the start of the test, where a maximum temperature of 53 °C was recorded on the surface of the pavement.

During the entire fatigue test, the pavement surface temperature varied between 36°C and -5.5°C, with most values comprised between 4 °C and 14°C. The mean surface temperature was 8.8°C, and the mean temperature in the middle of the bituminous layers was 9.0°C. These relatively low temperatures were adequate for testing fatigue resistance of the mixes.

Table 5: Loading conditions during each test phase

	Rutting test	**Fatigue test**	
Period	Summer 2017	November 2017 - February 2018	February – march 2018
Speed	43 km/h	76 km/h	43 km/h
Transverse wandering	+/- 26 cm	+/- 52 cm	+/- 52 cm
Surface Temperature: Min-Max	>30°C	-2.2°C ; 36.3°C	-5.5°C ; 26.7°C
Mean Temperature (middle of the layer)		9.2°C +/-4.7°C	8.2°C +/-4.2°C
Load (dual wheels)	65 kN	65 kN	75 kN
Number of loads	200 000	1 million	400 000

Rut depth measurements were made using a profilometer, with a laser sensor. The transversal profile of the pavement was measured on a width of about 1.4m. The maximum rut depth value was then determined. The measurements (4 or 5 measurements per section) were performed on each section approximately every 40 000 loads.

The evolution of mean rut depths (in %) during the test is presented on Figure 5.

Percentages of rutting are quite the same for the Mix 3 and EME2 sections (about 5%). Percentages of rutting of the Mix 2 (10.9%) and Mix 1 sections (10.0%) are higher. This difference occurred mostly at the beginning of the experiment while later the increase in rutting were stable and comparable.

Two hundred thousand cycles, with 65 kN dual wheel loads were applied during the rutting test. Severe test conditions were applied: high temperatures, low speed and narrow transversal wandering. At the end of the test, it could be concluded that:

- Rut depths increased rapidly on all sections during the first 10 000 cycles. This rapid increase could be due to post compaction, and also to the higher temperatures observed during these first 10 000 cycles.
- After 10 000 cycles, rutting continued to increase, but at a much lower rate, about 1 % of increase, until 200 000 loads for the EME2 and Mix 3 sections, and 2 % for the Mix 1 and Mix 2 sections. This indicates good performance of all the materials.
- The results obtained on the test track are consistent with the laboratory rutting tests. The materials presenting the best performance on the test track (EME2 and Mix 3 sections) also presented the best performance in the laboratory.

Concerning the origin of the rutting, the pavement profiles at the end of the rutting test indicate only downward deformations for all the material, which suggests more a post compaction mechanism (of the bituminous or granular layers) than a shear flow mechanism. However, it is not possible to conclude only from the surface observations if the rutting affects mainly the bituminous layers, or also the granular base. It will be only during the deconstruction of the pavement that it will be possible to cut trenches in the pavements, and to evaluate the deformations of the different pavement layers.

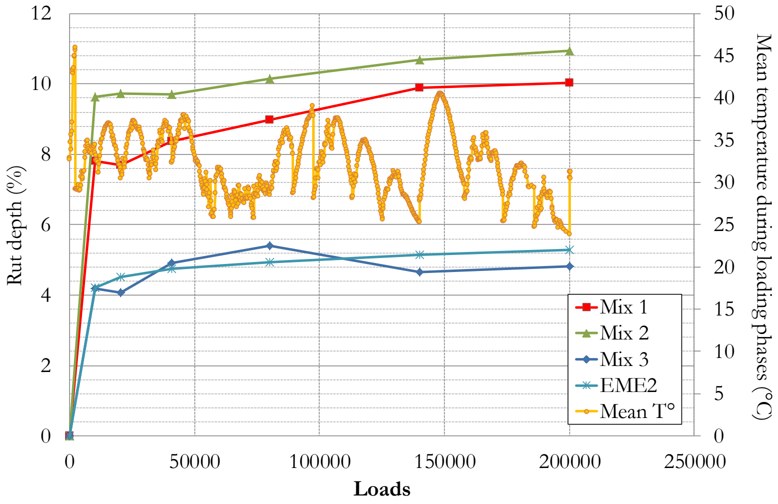


Figure 5: Evolution of rutting with the number of load cycles

Figure 6 presents the evolution of the extent of cracking, as a function of the level of traffic, on the four pavement sections. On the EME2 section, the first cracks were observed after 900 000 load cycles. Until 1.4 million loads, cracking increased regularly on this section, reaching 28% at the end of the test. The expected design life, from pavement design calculation, predicted 50 % of failure between 300 000 and 900 000 load cycles. The observations showed far better design life than initially calculated. The real thickness of the asphalt layer may have an effect. The EME2 structure had 10 cm asphalt layer thickness instead of 9 cm, which may predict longer life. A contrario, the Mix1 had 9 cm asphalt layer thickness which should have reduced its design life.

On the Mix3 section, the first cracks were observed after 1 000 000 load cycles. Until 1.4 million loads, the extent of cracking increased regularly, reaching 10% at the end of the test. On the Mix1 and Mix2 sections, no cracks were observed until the end of the test.

Pictures of the EME2 and Mix3 sections at the end of the test are presented on Figure 7. On these sections, the following crack patterns were observed: first, very fine isolated transversal cracks appeared (marked in white on Figure 8). Then, under traffic, these cracks started to open, and fines started to come out. Other thin transversal cracks developed nearby. The cracks marked in blue appeared at 1.1 million loads, in orange, at 1.2 million loads and in pink at 1.3 million loads.

The transversal orientation of the cracks is typical of fatigue cracking observed on the IFSTTAR APT, under dual wheels for pavements with thin bituminous layers [19].

These results clearly indicate that the EME2 section started to deteriorate first and that the three sections with bio-based materials presented a better behaviour, despite a slightly higher layer thickness for the EME2 or a slightly lower layer thickness for Mix1. These results differ from those of laboratory fatigue tests, which indicated the best fatigue resistance for the EME2 material.

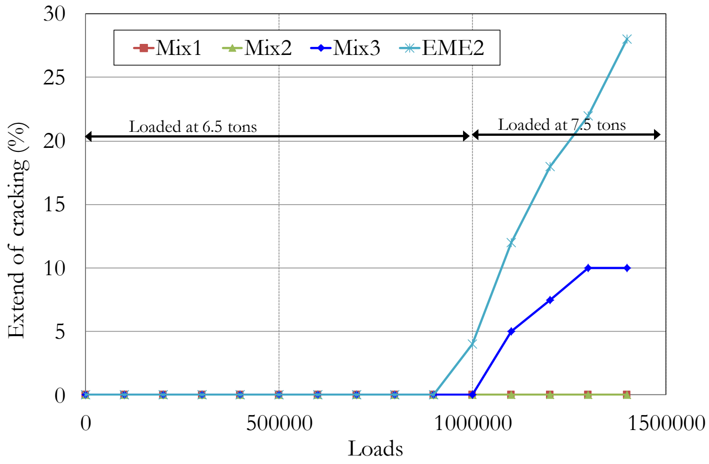


Figure 6: Extend of cracking, in percent, on the four sections

(a) EME2 section

(b) Mix3 section

Figure 7: View of the cracks on the EME2 section (a) and Mix3 section (b) after 1.4 million loads

2.2. Chemical properties evolution

The microsampling concept presented in Figure 8 begins with sampling the pavement using a hammer drill equipped with a 12.7 mm drill bit and vacuum dust collector [20]. For this project, about 10 holes were drilled 13 mm deep and the dust from each hole was collected to obtain about 100 g of material. This material constitutes the surface layer where most of the pavement oxidation occurs. The binder portion of the drilled dust was then extracted from the aggregate/fines portion by washing the samples in a mixture of 85:14.25:0.75, toluene:ethanol:water by volume. The samples were then centrifuged and filtered to remove the fines from the binder portion. The solvent was removed from the resulting solution using a rotary evaporator. Rheology of the recovered binders was then measured on a DSR with 4 mm parallel plate geometry [21].

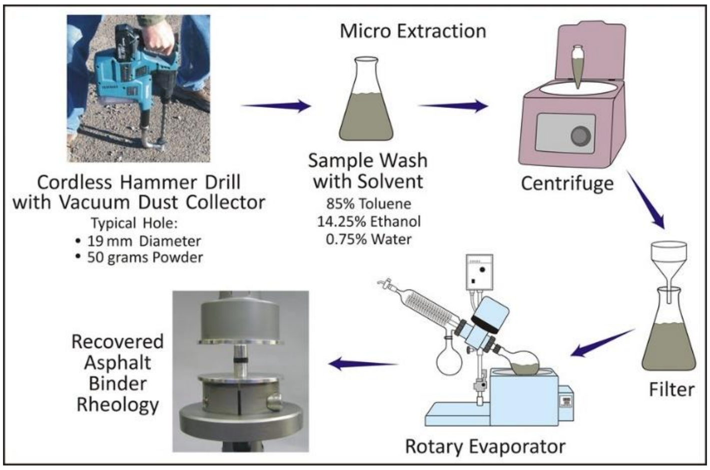


Figure 8: Micro-sampling concept

Figure 9 shows DSR results from the low temperature performance grading measurements for the extracted binders from the top 13mm of Mix1, Mix2, Mix3, and EME test section that were measured via 4 mm DSR after 5 months. These include two different components, Ts and Tm, respectively the critical temperatures for the stiffness S and the slope of the stiffness versus loading time m-value, considered as a parameter measuring relaxation ability of a binder. ΔTc parameter is defined as Ts-Tm where a positive number indicates a stiffness controlled sample and a negative number indicates a relaxation controlled sample. Upon aging, bituminous binders are known to become more m value controlled or more relaxation controlled as ΔTc becomes more negative [22]. Discussions are ongoing in the US at the Federal Highway Administration Binder Expert Task Group on a limit for this parameter obtained from the low temperature Superpave grading using the Bending Beam Rheometer. Figure 9 shows that Mix1 and Mix2 have less negative ΔTc values than the EME2 control and should, therefore, perform better with respect to cracking. Test track results in Figure 6 reveal this is exactly what occurred. Mix3 is a more complicated case as additional analyse did not highlight the full presence of the bio-additive. The root cause needs further investigation. It may be something happened during extraction and recovery or representatives of the sample Regardless, the corresponding extracted binder Tm, Ts, and ΔTc are all slightly better than the EME2 control. This is also consistent with the cracking performance data in Figure 7.

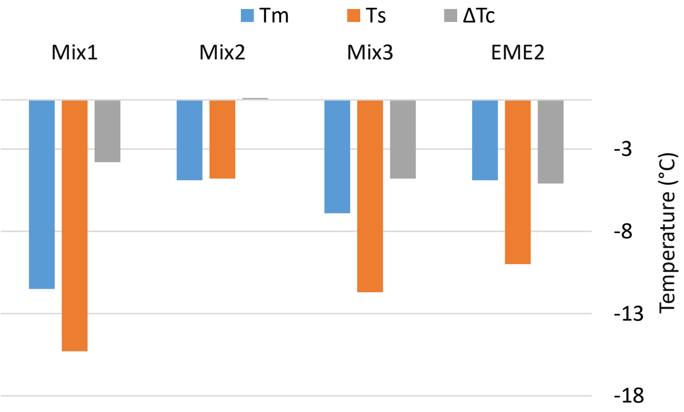


Figure 9: Low temperature DSR values of binders after 5 months on the test track

3. AIRBORNE EMISSIONS

3.1. Background

The new Constructions Products Regulation (CPR, 305/2011/EU) puts emphasis on a life-cycle perspective and on sustainability in a way that is comparable with the Re-Road project. CPR also stresses the importance of evaluating emissions of particles, toxic gasses and volatile organic compounds (VOC) to outdoor air and the working environment. Test methods developed to measure these emissions related to the life-cycle of asphalt can thus be of great value in relation to declaring the performance of RA (e.g. EPD, Environmental Product Declarations). Emissions to air might be an important issue in relation to the design of RA-recycling. Depending on the performance of the ”RA-product”, alternative actions are available e.g. destruction, low temperature or high temperature recycling.

IFSTTAR has developed a fume generation system in the laboratory which allows eliminating the fume condensation risk in the stack and in the Total Organic Compounds emitted (TOC) sampling line by adding heating devices. The goal of this asphalt fume generator is for it to be used as a predictive test, so as to forecast the amounts and the nature of fumes generated by bituminous mixtures, in different emissions scenarios. To achieve this purpose, the experimental principle is to mimic the different steps of bituminous mixtures (including Reclaimed Asphalt – RA) emissions from the manufacture to laying on road sites.

The aim of this work is to show the research program and the results dedicated to the assessment of BioRepavation Mix on fumes emissions during mixing in temperature.

3.2. Experimental set

The IFSTTAR prototype [23][24][25][26]was composed of an asphalt mixer which allows preparation of 80 kg of asphalt mixtures according to the EN 12697-35 standard. Aggregates and bitumen are closely mixed at the required temperature at a defined stirring speed during a specific time. During the entire mixing process, the mixer thermos-regulating system allows keeping temperature constant. In the case of bituminous mixtures fumes, it can be assumed that high temperature mixing allows bitumen stirring and thus fume emissions. In order to collect fumes emitted from the mixture, a stainless steel stack has been linked to the mixer. One opening at the top of the stack allows the positioning of the sampling probe. As emissions are generated, they are fed into the stack. To avoid condensation phenomenon into the stack, heated cables have been added.

After the fume generation and their transportation in the stack, fumes reach the sampling area at the top of the stack. At this place, a probe is used to sample the TOC. As in the stack, a heated probe and a heated line between the probe and the TOC analyzer have been used to eliminate any condensation. The probe and the Flam e ionization detector (FID) line are heated to the fume temperature measured just above asphalt material in the mixer.

Fumes analysis

The continuous sampling and analysis of TOC are carried out by a portable and automatic total hydrocarbon measuring equipment (SRA-model 901 MET-NMET/TOC Mercury). The device is calibrated by using propane gas. The factor to switch from mg/kg to EqC/m3 is 1.607. [ref AFNOR NF X 12619, 1999]

This TOC continuous measurement allows to derive a curve plotting the mass concentration of the emitted total organic compounds “TOC(e)” in the case of mix with RA according to time (Figure 1). By definition, TOC(e)max corresponds to the maximum concentration measured by the analyser during the test. From this graph, the instantaneous mass of carbon equivalent noted MTOCInst is calculated by the following equation: MTOCInst = TOCt x Volume sampledt where: TOCt is defined as the instantaneous TOC concentration at an instant t (see Diagram A in Figure 1) and the volume sampled (at t) is defined as following: FID sampling flow (L/s)×FID sampling time (s).

Then by adding up the instantaneous (see Diagram B in Figure 1), the final curve of cumulative mass of TOC MTOCCum according to time is determined. The two types of curves used, TOC and MTOCCum, are represented in Diagram C in Figure 10.

A specific protocol has been developed at IFSTTAR to generated fumes from asphalt mixtures, from asphalt manufacture to its laying on road sites. The development of this new procedure has been based on two observations. The focus is on the processing of asphalt mixe from the plant to the road site and have pointed out four main moments when asphalt is set in motion (Figure 11): Mix manufacture, Mix transfer from the plant silo to the truck, Mix transfer from the truck to the finisher and Mix dispersion on the finisher screw. Therefore, to mimic these different steps on a laboratory scale, the aforementioned fume generation protocol has been divided into four mixing periods. Each mixing period lasts four minutes, interspersed with 10-minute periods of time off. However the protocol is not calibrated to actual real emissions but meant to ensure detectable emissions.

As with the fume generation protocol, a sequential sampling process is also used. The aim is to compare the emission potential of the different fume generation steps. TOC will be analyzed continuously without sequences, and mixing periods will be marked on the TOC graph. From these initial data, a cumulative mass will be calculated for each sequence.

Table 6 gathered the experimental program dedicated to the fume emissions from bituminous mixes made of different content of RAs, added fresh binders and additives.

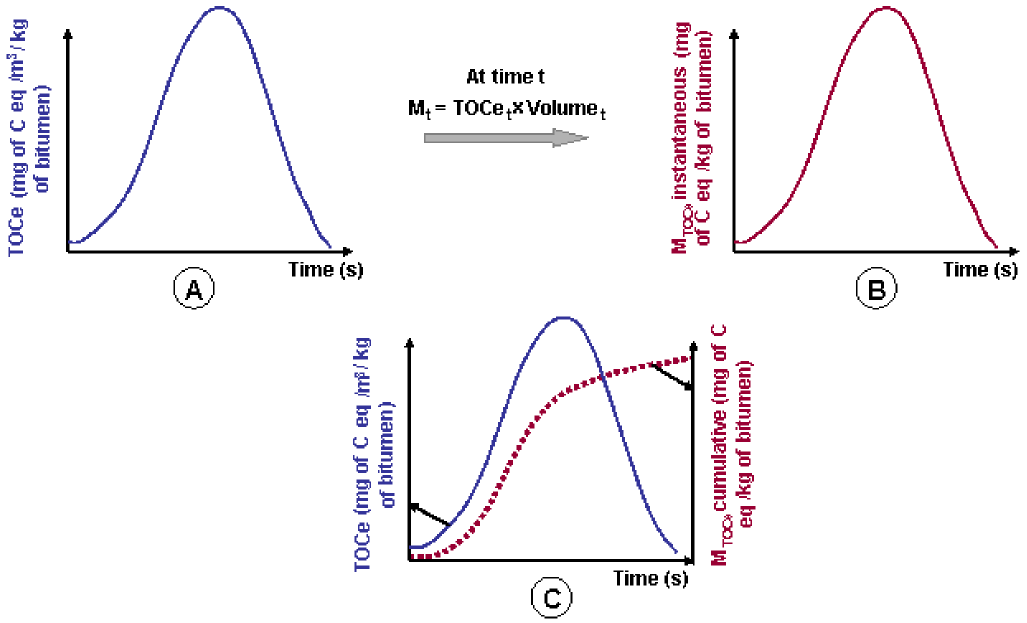


Figure 10: Emission curves of TOC (A), MTOCInst (B) and MTOCCum (C).

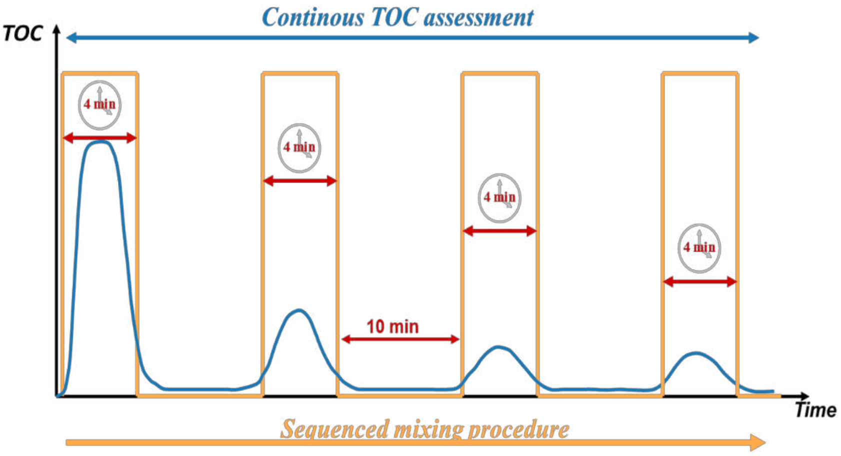


Figure 11: Fumes protocol generation in laboratory

Table 6: Experimental plan for fume emissions evaluation

Formula	Name	Mix	RA content (%)	Fresh binder	Binder content (%)	Additive content (%)	Manufacturing temperature (°C)
Control	EME	A	20	French 20/30	4,800	-	175
	GB5	A'	50	French 50/70	2.800	0.000	150
Bio Repavation	GB5 Biophalt	B	50	Biophalt	2.800	0.000	120,150,180
	GB5 Sylvaroad	C	50	French 50/70	2.700	0.100*	120,150,180
	GB5 EMS	D	50	French 50/70	2.800	0.135	120,150,180

3.3. Results

Repeatability was investigated for GB5 Mix (Mix A'). As shown on Figure 12, two tests were carried out and curves exhibit the same trend and appear as repeatable for identical experimental conditions. These results highlight the limitations of the test carried out, but the observed scatter still allows one to discriminate the various parameters effects.

First, TOC curve and cumulated TOC mass of two GB5 mixes (Mix A') measured at 150°C by the FID analyser are shown in Figure 12. For this mixture, the outline of the TOC curve clearly displays the four mixing sequences by distinct "emission peaks". This behaviour confirms the impact of mixing on fume generation: only mixed material generate fumes.

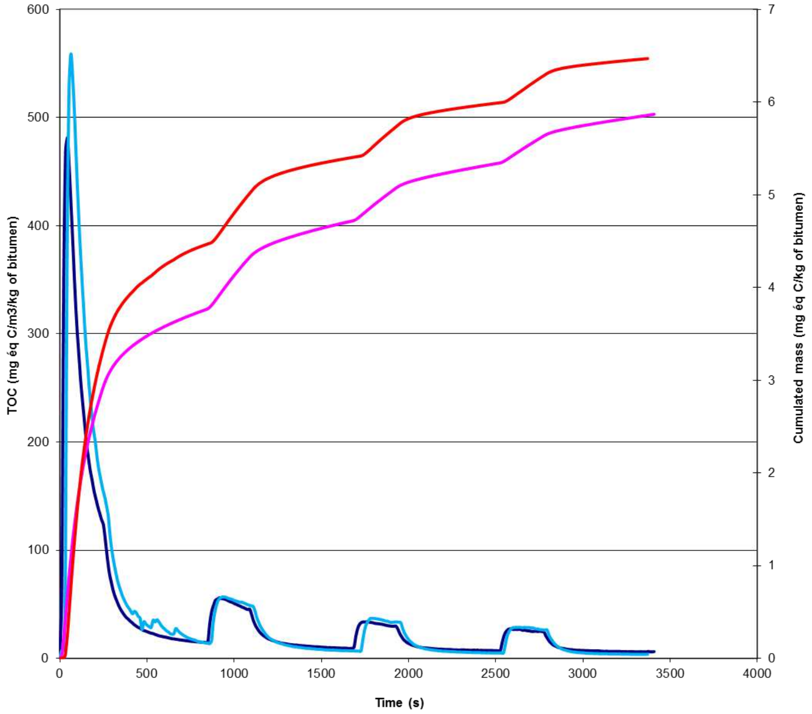


Figure 12: TOC and cumulated mass of TOC versus time for GB5 mixes (2 repetitions of Mix A') at 150°C.

By comparing the cumulated TOC mass curves of the GB5 mixes (with 50% of RA at 150°C), it appears that their emission levels are binder dependant (Figure 12). The incorporation of bio-binder/bio-additive increases the cumulated TOC mass from 8.6 for reference material to a range of 9.4 up to 11.1 mg of Ceq (for 50kg of asphalt). GB5 results are close to EME (with 20% of RA at 175°C, Mix A) fume behaviour (10.4 mg of Ceq) for an asphalt amount studied of 50 kg.

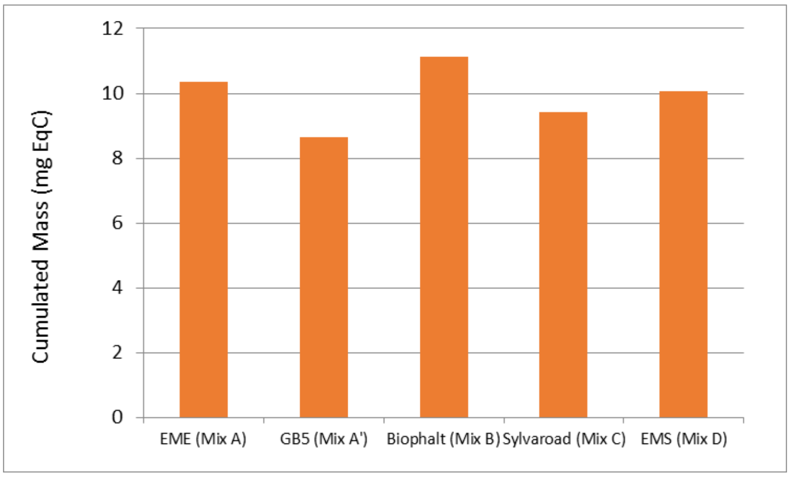


Figure 13: Cumulated TOC mass (explained by 50kg of asphalt) after 4 mixing-rest periods for the EME mix at 175°C and all GB5 at 150°C

4. CONCLUSIONS

In order to understand whether bio-recycled asphalt mixtures can be implemented in road pavements, a full scale accelerated test was performed at IFSTTAR to validate the performance of the three mixes obtained by using proprietary bio-materials as recycling agents for asphalt mixture with high-content RAP. These mixes were tested simultaneously with a reference EME2 material, which is a high performance asphalt mix for base layers. From the findings summarized above is possible to conclude that

- Bio-based materials of different nature could be successfully and efficiently used to partially or totally replace petroleum-based products as recycling agents to design durable recycled asphalt mixtures. This can help reducing the dependency of the asphalt industry from the oil industry
- The three different bio-recycled asphalt mixtures present better fatigue performance in situ than the reference EME2 mix, which is considered in France as a high performance base layer material. This confirms that these mixes can be used successfully for road construction.
- The non-destructive microsampling method seems very appropriate for surveying binders at various depth of the pavement, as a function of in-service time.
- The 4mm DSR and IR are very appropriate testing tools to accommodate the small amount of binder recovered from the microsampling method and to characterize the binder aging and embrittlement.

Measurements of fume emissions were performed on bituminous materials to characterise total organic compounds generated by asphalt material in temperature utilising an IFSTTAR experimental device and protocol. Parameters studied are the binder nature and mix formula. This laboratory study shows a strong link between bituminous material composition and their emission potential.
At the usual manufacturing temperature, 150°C, mix with EMS (Mix D) no additional fumes are observed in comparison to the reference mix (Mix A) or mix with no additive (Mix A').
At the usual manufacturing temperature, 150°C, mix with Sylvaroad (Mix C) no additional fumes are observed in comparison to the reference mix (Mix A) or mix with no additive (Mix A').
Concerning, mix with Biophalt (Mix B), the best emission performance in comparison to reference mix A is below 150°C.

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