



**HAL**  
open science

## High modulus asphalt mixes with high rate of RA: what does it happen ?

Yves Brosseau, Fabienne Farcas, Virginie Mouillet

### ► To cite this version:

Yves Brosseau, Fabienne Farcas, Virginie Mouillet. High modulus asphalt mixes with high rate of RA: what does it happen ?. Congrès Eurobitume Euraspalt, EE2012, Oct 2012, Turkey. 13p. hal-00875545

**HAL Id: hal-00875545**

**<https://hal.science/hal-00875545>**

Submitted on 22 Oct 2013

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

## High modulus asphalt mixes with high rate of RA: what does it happen?

Yves Brosseaud, French Institute of Science and Technology for Transport, Development and Networks (IFSTTAR), France

Fabienne Farcas, French Institute of Science and Technology for Transport, Development and Networks (IFSTTAR), France

Virginie Mouillet, French Regional Laboratory of Bridge and Road (LRPC) of Aix-en-Provence, France

### ABSTRACT:

Since more than ten years, the focuses on environmental aspects have lead to a need to adapt technical solutions for road applications regarding the sustainable development. In France, to answer to these preoccupations, the Enrobés à Module Elevé (EME - High Modulus Asphalt mixes, in english) give, since more than 20 years, an excellent solution to reduce the use of materials while maintaining a very long service life road structure. Similarly, the hot recycled asphalt mixes with high rate of RA (up to 50%) had shown a good efficiency to improve the environmental aspect, while showing a good mechanical behaviour.

This article presents the main characteristics of a job site which combine these two techniques, namely an EME with 50 and 65% of RA content. The main keys of success are developed, in terms of homogeneity of RA (wearing course on motorway), preliminary laboratory mix design, new mixing plant with two separate drums, where one is specially dedicated to the re-heating of RA and quality control. This paper describes the asphalt mix performance of the different asphalt mixes, like complex modulus, fatigue and rutting resistances, (preliminary study, mix from the plant or obtained in laboratory). This study is well completed by some researches on the properties of the binders (original binder from RA, new added hard bitumen 10/20, recovered binder from recycled mix). Not only the conventional characteristics, but also the rheological and structural performances (infrared spectroscopy, Size Exclusion Chromatography, IATROSCAN, asphaltenes content) are described.

### 1. Introduction

Since the last ten years, the focuses on environmental aspects have lead to a need to adapt technical solutions for road applications regarding the sustainable development. In France, it was a long development of new technologies to retreat in place the roads, to use the refuse products from the industry (granulated or steel slag, pulverised fly ash, crushed demolition cement concrete,...), or to reduce the thicknesses of wearing course (very thin or ultra-thin asphalt mixes), and so on, to answer to these preoccupations. Another way was to reduce the consumption of non-renewable resources (aggregates and also bitumen) by using Enrobés à Module Elevé (EME - High Modulus Asphalt mixes), since more than 25 years. The thickness reduction can reach to 30 – 35% less compared to traditional flexible pavement. This technique presents an excellent solution to reduce the use of materials while maintaining a very long service life in road structures. Nowadays, it is also possible to produce EME with warm technology. Similarly, the hot recycled asphalt mixes with high rate of RA (up to 50%) had shown a good efficiency to improve the environmental aspect, while showing a good mechanical behaviour.

This article presents the main characteristics of a job site which combines these two techniques, namely an EME with 50 and 65% of RA content. The main keys of success are developed, in terms of homogeneity of RA (wearing course on motorway), preliminary

laboratory mix design, new mixing plant with two separate drums, where one is specially dedicated to the re-heating of RA, and quality control. This study is well completed by some researches on the properties of the binders (original binder from RA, new added hard bitumen 10/20, recovered binder from recycled mix), and the way to prepare in laboratory the recycled bitumen of the recycled asphalt mix.

## 2. Presentation of job site

### 2.1 General properties of the job site

For many years, the concessionaire of highways in the North and East of the France (SANEF) was interested in development of innovative solutions, to modernize its network, while remaining attentive to the good management of its network and economic concerns. It was on these motorways that appeared the first porous asphalt, in the years 1985 and the first use of recycling at high rate (40 and 50%) of these porous asphalts. EME were also employed for more than 15 years, such as maintenance of the slow lane, or rehabilitation (reinforcement) of road pavement. These EME are aged of 7 to 8 years and recomposed from recycled asphalt (RA) at the rate of 25-30%.

A strengthening of pavement site took place in 2007 and 2008, on a highway in the North of France, supporting a very important heavy traffic (more than 1000 heavy trucks per day). A milling thick asphalt (béton bitumineux sémi-grenu - BBSG) wearing course (7 cm thick) was necessary due to technical reasons (wear and polishing). The strong demand by hard asphalt binder (10/20 or 15/25 penetration grade) for the manufacture of EME, increased by the use of both new pavement and building, have lead to some restrictions in the deliveries of the binder, and therefore the need to reduce consumption of raw materials and energy. The recycling with high rate on Highway, for the manufacture of the HMA is therefore essential.

**Picture 1** : Benninghoven continue mixing plant 450t/h



The first manufacturing (2007) of EME with 50% of RA was conducted in a mixing plant "double barrel" Astec. The production was 38 000t of EME recycled at 50%. In 2008, a mixing plant Benninghoven (see photograph 1), with a capacity of 400 t/h at 50% RA, equipped with two separate drums, allowed a recycling rate of 50 to 65%. The temperature of output HMA was 170 to 175 ° C (temperature of the RA output 110 to 120 ° C, temperature of the new aggregate approximately 220 to 240 ° C). Production controls have shown a good compliance with the specifications of the market, and a good regularity of all results. Several kilometres were applied using strengthening EME using RA at 50% and 65%, a test section of reference (400 m) with RA 0% was done, to follow the behaviour in time. After 4 years in service, the results are very good (see below the performances of mixes after one year of service).

## 2.2 Characteristics of components

In 2007, detailed preliminary mix design studies and applications of test section in EME with 65% of RA have lead to the final product. 65% of material came from the original asphalt mixture (BBSG 0/10, 6 cm thick), obtained after milling (with 4 machines) an old wearing course in service since more than ten years, and screened at sieve 20 mm.

The milled BBSG was very homogeneous:

- in granularity after milling, the maximum size was close to 25 mm, with a few agglomerates and platelets, eliminated by screening,
- in granular composition (range 3 to 4% in intermediate screens, after stripping binder test in solvent), the fines content is increased by 1.5 to 2% from the original product, due to the milling operation, but it is also very regular,
- in bitumen content (range  $\pm 0.2\%$ ) and residual properties (3 extractions, made by IFSTTAR, confirmed the preliminary results of the company, based on the classic characteristics of penetration and Ring & Ball, and show a low dispersion).

The characteristics of composition of this RA (old BBSG) are presented in table 1.

**Table 1** : grading and binder content of RA (BBSG), average of 4 determinations

Passing 0,063mm (%)	Passing 2 mm (%)	Passing 6 mm (%)	Binder content (%)
75	46	11,5	5,5

The binder recovered from RA (BBSG) presents a medium and normal hardness for old thick asphalt, after aging in service. It corresponds to a 20/30 penetration class bitumen, which originally was a 35/50 (according to EN 12591).The aggregate added came from a quarry, it is a limestone of size fraction: 10/20 mm, incorporated at 35%.

The added bitumen (or new bitumen) is a quite traditional hard bitumen of 10/20 penetration grade, at a content of only 1.6%A. This represents a total binder content of 5.2% in the EME after recycling (including 3.6% of old binder coming from RA). The hypothesis is that all the old binder can be available in new recycled binder, with the new bitumen. This hypotheses is supported by the results in term of binder recovered from HMA with 65% of RA manufactured in laboratory or in field, regarding binder content and properties (see in paragraph 3).

## 2.3 Compositions of the mixes

The different compositions of HMA with 50 and 65% of RA, tested in the study or applied on job site are presented on Table 2, the grading compositions are in Table 3.

**Table 2** : composition of HMA 50 and 65%

Formula	HMA 50 % (2007)	HMA 65 % (2008)
Limestone added 10/20	28,3	34,4
Limestone added 6/10	12,7	-
Limestone added 4/6	6,8	-
Filler added (limestone)	1	-
RA (BBSG milled)	48,7	63,9
New hard bitumen 10/20	2,6 (grade 15/25)	1,6
Total Binder	5,35	5,25
Richness modulus (K)		3,4

**Table 3** : grading composition of HMA 50 and 65%

Sieve (mm) Passing( %)	0,063	2	6	10	14	20
HMA 50%	7,5	29	50	70	84	99
HMA 65%	7,1	28	49	64	75	97

### 3. Performance and structural characteristics of the asphalt binders

#### 3.1 Program of tests and main results

In order to assess the dispersion on :

- preparation tests: recovery binder on RA and HMA 65% coming from job site,
- HMA 65 % prepared in laboratory,

all the different kind of tests were made twice (preparation and tests), by two laboratories (IFSTTAR, AIX LRPC).

The SARA (Saturated, Aromatics, Resins, Asphaltenes) fractions, colloidal structure and oxygenated species (carbonyl and sulfoxide groups) were respectively determined by IATROSCAN, HS-SEC (High speed size exclusion chromatography) and Fourier Transformation Infra-Red Spectroscopy (FTIRS).

These tests were carried out at IFSTTAR on the binders prepared independently (extracted from asphalt mix, ageing RTFOT) by two laboratories (IFSTTAR, AIX LRPC). Details of the methods are provided elsewhere [2].

**Table 4** : Synthetic results on classical tests (penetration, Ring and Ball, Fraass) and complementary (Asphaltenes, IRTF, BBR) characterisation for binders from two laboratories preparations (extraction included) and tests

Binder	Extract*	Test	Pene	R&B	FRAASS	%Asph.	IRTF		BBR	
							Carb.I	Sulfo I	T <sub>s</sub>	T <sub>m</sub>
New 10/20	Aix	Aix	13	64,8	-1	13,6	0	1,3	-7,3	-8,9
	IFSTTAR	IFSTTAR	15	65		-				
New 10/20 +RTFOT	Aix	Aix	9	68,6	-2	14,4	0	2,1	-7,8	-10,2
	IFSTTAR	Aix	9	69,8		14,7				
	IFSTTAR	IFSTTAR	11	69						
Extract RA	Aix	Aix	22	62,6	-9	16	4,5	12	-15,4	-14,7
	IFSTTAR	Aix	22	62,4		16,5				
	IFSTTAR	IFSTTAR	22	61,2						
Extract HMA65% Field	Aix	Aix	14	67	-6	17,2	4,6	10,8	-12,4	-10,9
	IFSTTAR	Aix	13	68,2		16,3				
	IFSTTAR	IFSTTAR	16	68,2						
Extract HMA65lab	IFSTTAR	IFSTTAR	15	66,6						
Recycled binder in lab	50 Aix	Aix	17	64,2	-4	15,6	2,7	5,5	-11,7	-11,2
	65 Aix	Aix	14	65,8	-4	15,6	2,6	6,8	-11,9	-11,7
	80 Aix	Aix	13	66,4	-4	16,8	3,1	6,3	-14,6	-13,2

\* Extract = preparation, or even sample selection (New binder), or extraction from asphalt mix (RA, HMA65% site or laboratory) or RTFOT, or mix in laboratory (recycled binder at different rate : 50; 65 and 80%)

One test on the preparation of "recycled binder" in laboratory (Aix LRPC) was made to produce a binder which could have the same characteristics that the binder present in EME 65%, according to the following protocol, trying to reproduce what happens in the plant mixer:

- heat Xg (65g for RA 65%) to extract binder from RA, directly in the penetration recipient, at 130°C during 30 min,
- heat 100g of new hard bitumen after ageing RTFOT (classical test at 163°C), directly in the penetration recipient, at 180°C during 30 minutes,
- take at hot temperature 35g of this added binder, add to the 65g recovered from RA,
- homogenize the mix, by agitation in sand bath (in order to better stabilize the temperature, and avoid peak of temperature) at 160°C, during 3 minutes.

This binder was analysed in SARA composition, and by other tests. Two other preparations of "recycled binder" in laboratory were made at 50 and 85% rate of "RA".

The tests applied are the conventional ones and the Bending Beam Rheometer test in accordance to the European standards, including the asphaltenes content according to French standard NF T60-115, in practice since January 2010. The LCPC (IFSTTAR) methods have been applied for the binder recovery by hot extraction, and the Infra-red Spectroscopy for determination of Carbonyl and Sulfoxyde indexes. Some other tests have been used, like Fraass and BBR test, to give some information at low temperature, which is an important issue for the hard bitumen. It is important to note that commonly no low temperature cracking problems are reported in sections where EME is used, even with low temperature being around  $-20^{\circ}\text{C}$  in the East of France.

The main results on this test program are summarized on table 4.

### 3.2 Results analysis on classical tests (penetration, Ring and Ball, Fraass)

All the results, penetration and R&B, for the same nature of binder are strictly the same, even if the preparation or test is carried out by a different laboratory (IFFSTAR or Aix LRPC). The progression of the results follows the logical process, namely the range from the most hardening to the "soft", for penetration characteristic:

New hard binder + RTFOT < New hard binder = Extract HMA 65% (lab or field) < Extract RA

The differences, in term of R&B, are low, so that the classification stays approximately the same. It would seem, in this case, that the results follow the mixing law of the bitumens.

There is no significant differences between Extract HMA 65%, Extract RA, for asphaltenes content (16,5 / 17), even the bitumen added present a low asphaltene content.

The behaviour classification at low temperature of binder indicated by Fraass temperature and BBR (Ts value) is also the same, the range from the most sensitive to the lowest:

New hard bitumen (with or without ageing) < Extract HMA 65% < Extract RA

### 3.3 Results on characterisation of ageing bitumen (FTIRS)

It is difficult to analyze the binders by carbonyl content because added hard bitumen (10/20) do not present carbonyl functions (new binder or after RTFOT), and the content in carbonyl is the same for the binder extract from HMA65 and RA.

Sulfoxyde content is also very low for added hard bitumen (10/20). It increases slightly after RTFOT (+ 0.9 point). However, the binder extracted from EME 65% presents a significantly lower content than the binder extract from RA (2 points), which could indicate a regeneration process of the binder recycled compared to the oxidation of old bitumen (RA).

The preparation of a "recycled binder" in laboratory, according to the method proposed, leads to a binder whose characteristics are well in accordance with the percentage of old bitumen (extract from RA), in the range from 50 to 80%, for all tests carried out, even if the gaps are low, the classification meets the logical progression. Only Fraass test does not account any difference, which is linked to the lack of sensitivity of the test.

### 3.4 Structure of bitumen (SARA fractions)

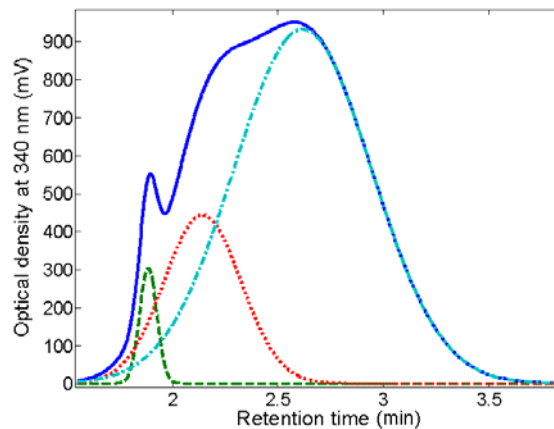
#### 3.4.1. High speed gel permeation chromatography (HS-SEC)

In order to investigate the molecular association phenomena, there were performed bituminous binder size exclusion chromatography (SEC) in particular experimental conditions, called "high speed chromatography" analysis ("HS-SEC"): high solvent flow rate ( $3.5 \text{ mL min}^{-1}$ ) and high sample concentration ( $30 \text{ g.L}^{-1}$ ). The choice of parameters is meant to obtain the closest chromatographic picture to the colloidal structure of bitumen, with chromatographic peaks evidencing molecular association. Some data may thus be inferred

on the quantity of associated molecules in the solution, and on the size distribution of such aggregates. [1]

**Table 5** : Main characteristics of the method used in HS SEC.

chromatographic column	Solvent	Concentration in sample	Flow speed of solvent	Detection
- $\mu$ styrigel bonding divinyl benzene - Porosity : 500 Å - size of grain support 15 $\mu$ m	THF for RPLC	3% in THF	3 mL/min	UV at 340 nm



**Figure 1** : Example of road bitumen chromatogram deconvolution analysed by HS-SEC.

**Table 6** : HS-SEC results, percentage of three components; binders from two laboratories

Binder		Agglomerates (%)		Micelles (%)		Inter micellar phase (%)	
		IFSSTAR	AIX	IFSSTAR	AIX	IFSSTAR	AIX
New hard bitumen 10/20	<b>Average (m)</b>	<b>2,8</b>	<b>2,4</b>	<b>16,8</b>	<b>17,1</b>	<b>80,4</b>	<b>80,5</b>
	St. dev.( $\sigma$ )	0,08	0,06	0,28	0,46	0,23	0,42
	$\sigma$ /m (%)	2,89	2,36	1,68	2,72	0,29	0,52
New hard bitumen 10/20 + RTFOT	<b>Average (m)</b>	<b>3,6</b>	<b>3,2</b>	<b>16,7</b>	<b>17,1</b>	<b>79,7</b>	<b>78,7</b>
	St. dev.( $\sigma$ )	0,03	0,02	0,72	0,46	0,74	0,10
	$\sigma$ /m (%)	0,90	0,50	4,32	2,72	0,93	0,13
Extract from RA	<b>Average (m)</b>	<b>5,1</b>	<b>4,8</b>	<b>11,8</b>	<b>13,0</b>	<b>83,1</b>	<b>82,2</b>
	St. dev.( $\sigma$ )	0,06	0,08	0,17	0,02	0,13	0,16
	$\sigma$ /m (%)	1,09	1,57	1,40	0,5	0,15	0,19
Extract from HMA 65% field	<b>Average (m)</b>	<b>5,4</b>	<b>4,0</b>	<b>15,2</b>	<b>13,8</b>	<b>79,4</b>	<b>82,2</b>
	St. dev.( $\sigma$ )	0,04	0,04	0,35	0,25	0,39	0,27
	$\sigma$ /m (%)	0,82	0,93	2,28	1,78	0,49	0,33
Recycled binder prepared in lab <sup>(1)</sup>	<b>Average (m)</b>		<b>4,2</b>		<b>15,0</b>		<b>80,6</b>
	St. dev.( $\sigma$ )		0,03		0,92		0,92
	$\sigma$ /m (%)		0,71		6,08		1,14

(1) Binder mix from 65% binder extract from RA and 35% new hard bitumen after RTFOT ageing

The chromatograms are registered by the “azure 4.6 of Datalys of equipment software”. The percentages of the three detected populations are calculated using a deconvolution program (“SEC analysis”), developed by E. Chailleux (road materials department of the IFSTTAR) [2], according to the example shown in figure 1. The results of HS-SEC are reported on the table 6, for the different nature and preparation of binder tested. The average, and standard deviation calculated came from 3 repetitions of the test.

In this study we are more interested by the oxidized compounds of the bitumen, especially asphaltenes clusters (interaction peak), because these molecule have a high influence on the behavior of binder, and of course for the asphalt mix.

The results on asphaltenes content, for different modalities, are a little higher for the binders extract or prepared from IFSTTAR to those provided by LRPC of Aix. Chromatographic analyses have not been made at the same time; this difference is partly due to the state of the chromatographic column that can evolve over time. Indeed the peak of interaction of a bitumen “Reichstett refinery” 35/50, we use as reference of the state of the chromatography column, was more intense during the test carried for IFSTTAR binder analysis (7.1%) than those practiced for LRPC of Aix. So it is one of the explanations of the small differences observed.

The conclusion is that the extraction method, lead to the same order of magnitude regarding the composition of the binder. This study is important to validate the efficiency of the binder recovery method (LCPC) to extract a relevant binder.

### 3.4.2. IATROSCAN

**Table 7** : IATROSCAN results, separation in SARA fractions, on binders two laboratories

		Binder extract from IFSTTAR					Binder extract from Aix				
		Sat. <sup>(1)</sup> (%)	Aro. <sup>(2)</sup> (%)	Résin (%)	Asph. <sup>(3)</sup> (%)	CI <sup>(4)</sup>	Sat. <sup>(1)</sup> (%)	Aro. <sup>(2)</sup> (%)	Résin (%)	Asph. <sup>(3)</sup> (%)	CI <sup>(4)</sup>
New hard bitumen 10/20	<b>M</b>	<b>1,5</b>	<b>47,3</b>	<b>29,6</b>	<b>21,6</b>	<b>0,30</b>	<b>1,8</b>	<b>48,5</b>	<b>27,9</b>	<b>21,8</b>	<b>0,31</b>
	$\sigma$	0,14	1,68	1,75	2,09		0,27	2,69	2,25	1,03	
	$\sigma/M$ (%)	9,3	3,5	5,9	9,7		14,9	5,5	8,0	4,7	
Liant d'apport 10/20 RTFOT	<b>M</b>	<b>1,6</b>	<b>43,7</b>	<b>31,1</b>	<b>23,6</b>	<b>0,34</b>	<b>1,9</b>	<b>48,4</b>	<b>28,0</b>	<b>21,7</b>	<b>0,31</b>
	$\sigma$	0,12	1,79	1,94	0,98		0,23	2,36	2,05	0,76	
	$\sigma/M$ (%)	7,4	4,10	6,24	4,14		12,3	4,9	7,3	3,5	
Extract from RA	<b>M</b>	<b>3,5</b>	<b>34,7</b>	<b>37,6</b>	<b>24,2</b>	<b>0,38</b>	<b>4,7</b>	<b>35,75</b>	<b>36,8</b>	<b>22,8</b>	<b>0,38</b>
	$\sigma$	0,33	1,53	2,07	0,75		0,67	1,68	1,78	0,65	
	$\sigma/M$ (%)	9,6	4,4	5,5	3,1		14,4	4,7	4,8	2,8	
Extract from HMA 65% field	<b>M</b>	<b>4,1</b>	<b>28,1</b>	<b>40,8</b>	<b>27,0</b>	<b>0,45</b>	<b>4,5</b>	<b>36,1</b>	<b>35,4</b>	<b>24,0</b>	<b>0,40</b>
	$\sigma$	0,33	1,20	0,93	0,61		0,58	1,51	2,11	1,30	
	$\sigma/M$ (%)	8,1	4,3	2,3	2,3		12,9	4,2	6,0	5,4	
Recycled binder prepared in lab <sup>(5)</sup>	<b>M</b>						<b>3,9</b>	<b>39,2</b>	<b>34,3</b>	<b>22,6</b>	<b>0,36</b>
	$\sigma$						1,03	1,81	1,67	1,62	
	$\sigma/M$ (%)						26,3	4,6	4,9	7,2	

<sup>(1)</sup> Saturated ; <sup>(2)</sup> Aromatic ; <sup>(3)</sup> Asphaltén ; <sup>(4)</sup> Colloïdal Index,; M : Average ;  $\sigma$  : Standard deviation;

<sup>(5)</sup> Binder mix from 65% binder extract from RA and 35% new hard bitumen after RTFOT ageing



Chromatography on silica rods separate molecules of a mixture according to their polarity. This separation technique is similar to a thin layer chromatography, the determination of SARA fractions being with a gas chromatography-flame ionization detection. Applied to the bitumen, this technique allows to separate the bitumen in generic families (saturates, aromatics, resins, asphaltenes) and to calculate the value of the index of colloidal instability (CI). The main results are presneted in the table 7.

In this study we are more interested by the oxidized compounds of the bitumen content: asphaltenes and resins. Compared to the values obtained by precipitation in n-heptane (NF T60-115), asphaltenes levels determined by IATROSCAN (Asphaltènes IATRO) are higher (table 7 and figure 2). Indeed, as shown by Torres et al.[3], some soluble compounds in n-heptane are not eluted with resins. These compounds, detected with asphaltenes at the foot of the silica baton, present an intermediate polarity between asphaltenes and resins, and are considered like "polar resins". On the other hand, it should be taken into account with the fact that the levels of asphaltenes are expressed as mass percentages while those given by IATROSCAN are calculated from the detection of a quantity of carbon atoms.

The asphaltenes content (IATRO) and resins content (table 7) are slightly higher for the extracted IFSTTAR binders as those extract from LRPC of Aix. The same remark is determined by HS-SEC on asphaltenes clusters. This difference can be explained by changes in the status of the freezing of the chromatographic column, and the reproducibility of the recovery of bitumen. For two laboratories, even though the differences are not significant, the classification is the same for Asphaltenes (heptane), Asphaltenes (IATRO) and resins, the range can be classified as follows:

$$\text{New binder} = \text{New binder} + \text{RTFOT} < \text{Extract RA} = \text{Extract HMA 65\%}$$

The values of IC follow the same classification (see figure 3).

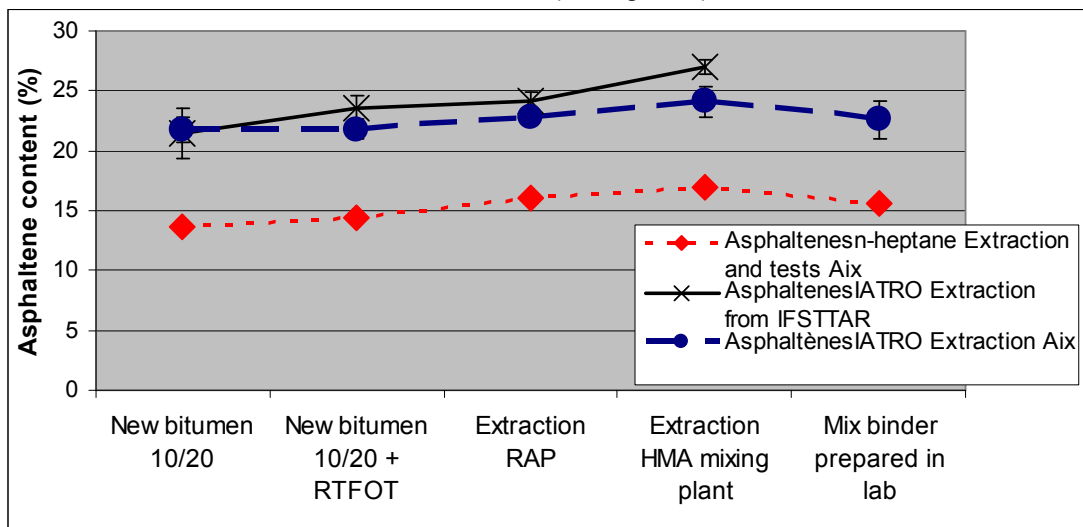


Figure 2 : Asphaltenes content

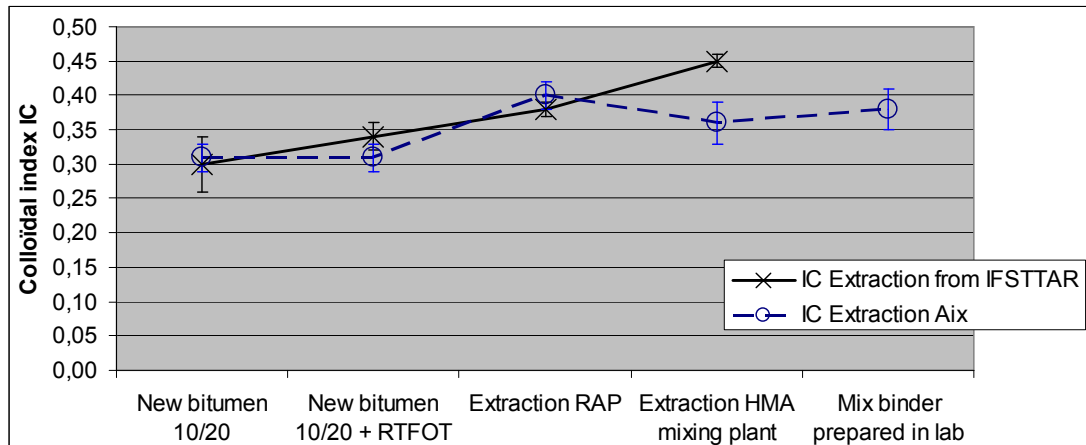


Figure 3 : Colloidal index (CI)

#### 4. Performances of asphalt mixes EME 50 or 65%

The asphalt mixes were studied in laboratory according to the French hot mix design method (Spanish version available in the IFSTTAR)[4]. A modification of the temperature of RA and aggregates was made to take into account the temperatures on plant in site. Temperatures recommended in the European standard are too low (RA / aggregate at 110° / 190°C) to ensure adequate heating and coating of aggregates and to produce EME at sufficiently high temperature. Tests have led to the following preparation conditions:

- new aggregate limestone 10/20 mm : 230 ° C for 12 h.
- RA (in a closed box) : 120 ° C for 2 h 30.
- new hard bitumen 10/20 (penetration grade) : 185 ° C for 4 h,

to have a recycled EME output of mixer (insulated and maintained at 180 ° C), at 150 ° C, temperature for properly preparing plates for testing, and good coating material.

The synthetic results of mix design, following the level 2 study of the French Mix Design Method (gyratory compactor, water resistance and rutting resistance), on HMA 65% is summarized in table 8. The results on EME 50% were approximately the same.

Table 8 : Mix design and mechanical performances of EME 0/20 class 2 recycled at 65%

Comparison of different studies HMA 65 % RA	Preliminary (company)	Study 2008 IFSTTAR	Specification HMA
<b>Gyratory Shear compaction</b> (NF EN 12697-31)			
V10 (voids %)	11	14	
V120 (%)	1,8	3,8	< 6
V200 (%)	1	2	
<b>Water sensitivity</b> (NF EN 12697-12)			
Duriez r/R %	90	95	> 75
<b>Rutting</b> (NF EN 12697-32)			
Rut at 30000 cycles (%)	5,9	3,1	< 7,5
Voids %	3,8	4	3 to 6

The conclusion is a very good behavior regarding all parameters : excellent workability (better than no recycling), very good resistance to water due to the use of limestone aggregate added (35%), and no significant permanent deformation, with the combination of old pure bitumen and hard bitumen added (1,7% of 10/20 penetration grade).

The mechanical performance, in terms of complex modulus and fatigue resistance, in two points flexion on trapezoidal samples, and constant deformation (fatigue) were indicated in table 9, on EME at 50% of RA prepared in mixing plant (2007 – new bitumen added 15/25 penetration grade) and on EME at 65% of RA prepared in laboratory or in plant, but compacted in lab to respect the densification criteria (3 to 6% voids).

**Table 9** : Mechanical performances of EME 0/20 class 2 recycled at 50% (2007)

Comparison of different modes HAM 50% RA – 2007	Size of sample base : 56 mm	Size of sample base : 70 mm	Specification HMA
<b>Modulus</b> (NF EN 12697-26) Flexion 15°C 10Hz (MPa) Phase angle 15°C 10Hz (degree) voids %	15 400 12,2 3,0	-	> 14 000  3 to 6
<b>Fatigue</b> in flexion (NF EN 12697-24) test conditions : 10°C – 25 Hz ε6 (micro-deformation) Δε6 (micro-deformation) Slope of fatigue voids % E modulus 10°C – 25 Hz Phase angle 10°C 25Hz (degree)	154 4,7 -0,145 2,9 18 950 8,2	152 7,3 -0,161 2,7 19 100 8,1	> 130   3 to 6

**Table 10** : Mechanical performance of EME 0/20 class 2 recycled at 65%

Comparison of different studies HMA 65 % RA	Preliminary (company)	Study 2007 IFSTTAR	Study 2008 IFSTTAR	Specification HMA
<b>Modulus</b> (NFEN 12697-26) Traction 15°C 0,02s (MPa) Voids % Flexion Test at 15°C 10Hz Flexion (MPa) Phase angle (degree) voids %	14 300 2 - - - -	- - 17 000 11,3 2,4	-  Lab. / Field** 17 000 / 17 550 11 / 10,4 3,5 / 4,0	> 14 000 3 to 6 > 14 000  3 to 6
<b>Fatigue</b> in flexion (NF EN 12697-24) test conditions:10°C–25 Hz ε6 (micro-deformation) Δε6 (micro-deformation) Slope of fatigue voids % E modulus 10°C – 25 Hz		120 / 129* 7 / 7,5 -0,192 / -0,149 2,8 / 3,2 19 650 / 10 850	Lab. / Field** 128 / 117 4,7 / 14*** -0,187 / -0,199 1,1 / 2,5 21 300 / 19 580	> 130   3 to 6

\* retesting of fatigue by changing the size of the test trapezoidal pieces: large base 70 mm instead of 50 mm (to take into account the maximum size 20 mm of EME, instead of 14 mm)

\*\* comparison between a manufacturing site in mix plant and laboratory (compaction plates according to the same energy with the laboratory plate compactor)

\*\*\* high dispersion, because test carried out on only 3 levels deformation of 4 samples (instead of 6 samples, in the current case).

The results of these mechanical tests led to the following findings:

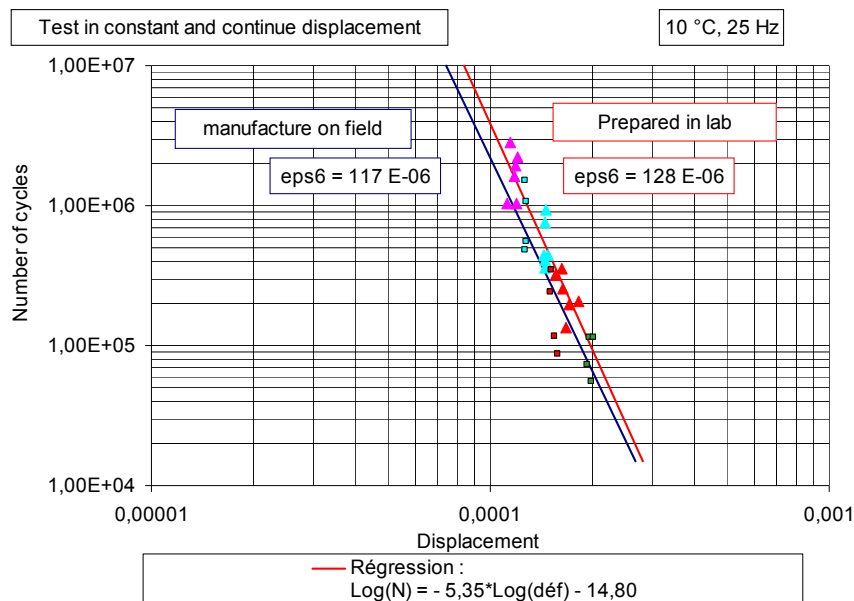
- EMEs recycled with 50 and 65% RA respect all the requirements of standard specification, for EME class 2 (traditional using according to [2]),
- the modulus is high, and fairly representative of a hard and “structured” bitumen, with a moderate aging, the modulus is 10% higher for the highest rate of recycled,

- duplication of testing complex modulus, due to the changes of the size of samples tested (modulus complex 15°C and 10 hz) and modulus before flexural fatigue test (10 ° C 25 hz) are very homogeneous and repeatable, the orders of magnitude of 15 500 MPa (EME with 50% RA) and 17 000Mpa (EME with 65% RA), as the value for pavement design are satisfied, without adversely on the behavior fatigue, even if has decreased moderated in fatigue behavior according to the increase in the recycled rate,
- fatigue strength decreases with the rate of recycled, lost on the site 15% on the fatigue test, going from 150 to 125 micro-deformations, from 50% to 65% RA,
- however, the resistance fatigue EME 65% remains in the specification limit, since the average value  $\epsilon_6$  is located near 125 micro-deformations, with normal dispersion, for a rate of recycled as strong.

Note: a very strong dispersion for the mixture prepared in mixing plant ( $\Delta\epsilon_6 = 14$ , double classic results), that could be explained by only 12 specimens tested, instead of the 18 in the general case, and the dispersion of the air voids content in samples tested.

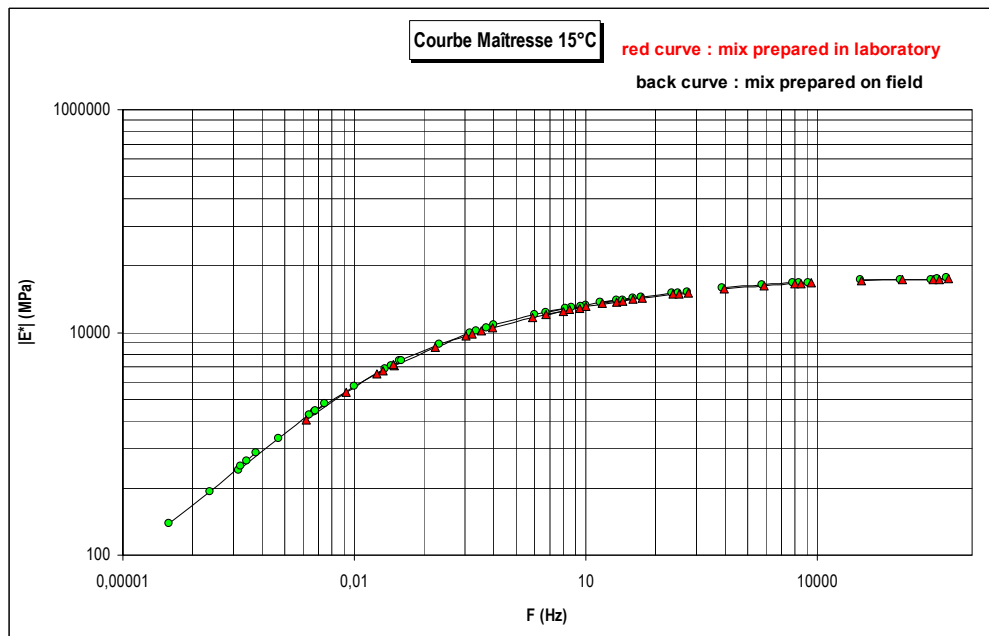
- highlights a greater sensitivity of the fatigue tests dispersion with higher recycling rate,
- characterization of EMEs manufactured in site or laboratory led to the same mechanical performances, given dispersions in field and the differences in composition and coated (void content). Thus, taking account of the differences in voids, between the samples produced in plant and in the laboratory, by formula of F. Moutier (regression of the plan experience fatigue – guide of French mix design), completely explain differences in fatigue for EME 65%: since passing from  $\epsilon_6$  117-123/ 124 (field) to 128 (lab). The illustration of fatigue behaviour and comparison of manufacture process are given in figure 4.

$\Delta\epsilon_6 = 3,3$   $\Delta\text{voids} (\%) = 6,3$  , thus  $\epsilon_6 = 117 + 6,3 = 123$  (same void content than in lab)  
or by the other formula  $\epsilon_6 = (-125 + 72TL - 4,85TL^2 + 3,3\Delta V)10^6 = 124,1$



**Figure 4 :** Straight line of fatigue on EME with 65% RA prepared in laboratory or on field

The rheological behavior of HMA recycled and prepared in the laboratory or on site is strictly comparable all over the master curve, as shown in the figure 5, at 15°C temperature. The modulus, at a frequency of 10 Hz, extend 31 000 to 400 MPa, for a range of temperatures from -10°C to 60°C. This is a characteristic of the HMA behavior.



**Figure 5** : Master curve of modulus on HMA 65% prepared in laboratory or on field

Tests of characterization of the HMA on site, by cutting plates, three sections at the recycled rate of 0%, 50% and 65%, after a year in traffic, lead to results of modulus (14 000 to 16 500 MPa) and fatigue resistance (115 to 130 micro-deformations), well comparable (taking account the dispersions due to manufacture and implementation in site, the differences in levels of voids were 3-4%, for example) with the results in the laboratory and in accordance with the specifications of the HMA [5].

All the results presented in this study tend to validate the method of study of recycled materials in laboratory with some adjustments to the preparation and manufacture. It allows to evaluate the orders of magnitudes of mechanical properties of the recycled asphalt, even at high rates of RA, and high performance as the EME, and to study the impact of the recycled rate.

## 5. Conclusion

With the “Grenelle” of the environment in France and in European community, commitments on emission reduction of greenhouse gases, taking into account the sustainable development has become essential in our modes of thinking road infrastructure. The recovery of materials from the road and highway has been demonstrated worth through numerous applications, made during more than 25 years. That allows a better technical assessment, including in terms of sustainability, but also on the conditions of increasing the probability of success.

However, there is still the need to improve, through research, the most favorable way to exploit the properties of residual materials in General and of the mix in particular, including for the surface layers, composed of noble materials: excellent aggregate and modified bitumen and aged so well structured to reconstruct of coated efficient and sustainable, as EMEs recycled at high rate. RA rates of 50 to 65% are possible, if the RA available presents a very good homogeneity (nature, composition, thickness, ageing,...), with a good quality control during construction, which is the case of motorways or major national roads.

An adapted study in laboratory with the tools of asphalt mix design and some modifications for preparation of samples allow realistic estimated performance and behavior of recycled asphalt, even with EME.

## 6. References

1. Brule B, Ramond G, Such C., "Relations composition-structure-propriétés des bitumes routiers - Etat des recherches au LCPC", Bulletin de Liaison Labo Ponts et Chaussées 1987;n° 148, 69-81.
2. M. Le Guern, E. Chailleux, F. Farcas, S. Dreessen, I. Mabile, Physico-chemical analysis of five hard bitumens: Identification of chemical species and molecular organization before and after artificial aging, Fuel 89 (2010) 3330–3339-81.
3. Torres J., González J.M., Peralta X., "Correlation between the fractionation of bitumen according to the methods ASTM D-4124 and IATROSCAN", Eurobitumen, Stockholm, 1993
4. Delorme JL, et al, "Manual LPC de ayuda en la formulacion de mezclas bituminosas en caliente", julio 2005, Etudes et Recherches des Laboratoires des Ponts et Chaussées, CR 39E, 185 pages – exist also in French and English version, same references.
5. Brosseaud Yves, "Reciclagem de misturas asfálticas: evolucao apos 10 anos e a situacao atual na França", 3° Salão de Inovação ABCR – 7° Congresso Brasileiro de Rodovias e Concessões – Foz do Iguaçu – October 2011
6. NF EN 12697-31 giratory shear compactor
7. NF EN 12697-12 resistance to water
8. NF EN 12697-32 resistance to rutting