BioRePavation: innovation in bio-recycling of old asphalt pavements, comparison between EU and US mix design specification systems

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ABSTRACT

The study presented here takes part of a larger project called BioRePavation. It aims at demonstrating that binders and additives from biomass can be used to increase recycling rate in bituminous pavement applications. A typical asphalt mix, incorporating 50%RAP, has been designed following the aggregate packing concept (GB5® type). Three biomaterials are used to partially or fully replace fresh binder. Hence, three innovative solutions are assessed at the binder and mix scales. European and American methodologies are used for comparison, expecting a potential implementation on both continents.

The main conclusion from this lab study is that 50% of RAP could be incorporated in hot mix asphalt along with appropriately selected additives/binders to reactivate the aged RA binder without compromising the performance of the asphalt mixture. A full scale accelerated loading test, planed as the next step in the BioRePavation project, will give relevant information to better understand the behaviour of these innovations for pavement construction.

Keywords: Reclaimed Asphalt, recycling, bioasphalt, rejuvenator, bitumen, asphalt mix

1. INTRODUCTION

The use of Reclaimed Asphalt Pavement (RAP) is widespread due to its availability and the need to reduce the consumption of non-renewable materials from the construction and maintenance of roads. Additives are becoming more widely used to help rejuvenating Reclaimed Asphalt (RA), and increasing compatibility between RA and Fresh Bitumen (FB), particularly in the case of high RAP content mixes (over 30-40% RAP). Moreover, an alternative way could be to totally replace FB by binder from biomass.

The present study deals with three innovative materials, already patented, aiming to reduce the use of virgin aggregates and petroleum bitumen for road maintenance and construction. Each innovation proposed involves a different type of bio-product, which not only differ by their molecular structure and processing but also by their working mechanism and interactions with asphaltic materials. As such they are considered to be complimentary solutions. These three bio-products represent solutions for most cases of RAP reuse that road owners may encounter. Kraton Chemical has developed a bio-based rejuvenator [1][2] used for a pre-treatment of RA. It has been designed especially to increase RA content up to 100%.

EIFFAGE has developed a bio-binder [3][4] designed for total replacement of bitumen in recycling technique. Iowa State University has developed a bioasphalt to increase RA compatibility with virgin materials.

The goal of the BioRePavation project [5] is to prove that these innovations can be implemented at full scale in different countries (especially in Europe and US). To be able to achieve this goal, the strategy described in the **FIGURE 1** is proposed. The main idea is to verify that these new materials behave well at full scale, in an accelerated and controlled environment. However, for a wider implementation, in order to check whether these innovations can be applied in other conditions, it is necessary to know if standardized lab tests are able to predict actual field performances. More precisely, it is proposed to work on both US and EU specification system at binder and mix levels.

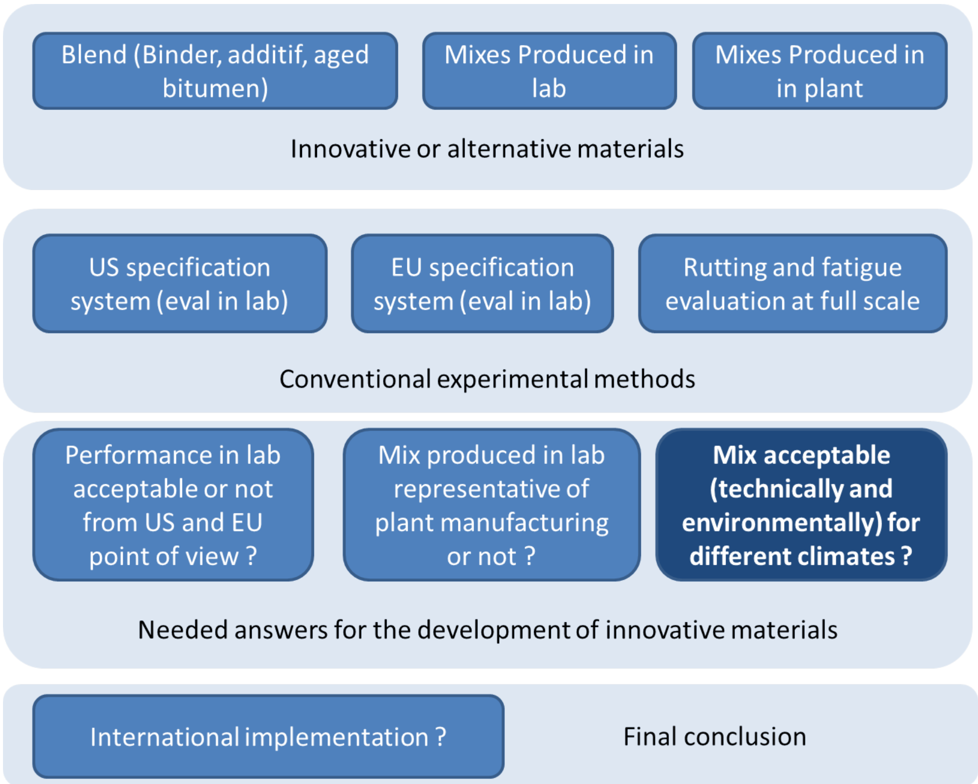

FIGURE 1. Principles of innovation assessment in BioRePavation: full scale experiment compared to specification system for actual implementation

The purpose of the work displayed in this paper is to assess, in lab, binder blends and the corresponding mixes using EU and US specification framework systems. After a first section describing all the materials used in this study, the mix design chosen here, including 50%RAP, is detailed. Firstly, the properties of the blends measured in lab are given and then the characteristics of the mixes are compared. For each case, both EU and US systems are used.

2. MATERIALS AND METHODS

2.1 Materials

All materials used in this study are listed in **Table 1**. BM 1 to 3 are the innovative biomaterials developed especially to increase recyclability of old asphalt. The Aged Binder (AB) has been extracted from both RA materials in order to be characterized independently. The fresh binder (FB) is a conventional pure bitumen, 50/70 pen graded. Three virgin aggregate fractions and two RAP fractions have been used for the mix design.

Table 1. Materials

Designation	Composition	Function	Commercial name	Company
BM1	Additive from Pine chemistry	Rejuvenator	SYLVAROAD ™ RP1000	Kraton
BM2	Tail Oil Pitch containing fatty acids + SBS + rosin	Bio-binder	Biophalt®	Eiffage
BM3	Epoxidized methyl soyate	Compatibilizer	EMS	Adventus & ADM
FB	Conventional petroleum bitumen (50/70)	Fresh binder		Supplied by Eiffage
AB	petroleum bitumen	Aged binder, extracted from RAP		
RAP 8/12 mm	AB content=2.9%			Supplied by Eiffage
RAP 0/8 mm	AB content= 4.4%			Supplied by Eiffage
Virgin Aggregate 10/14mm	Diorite			La Noubleau
Virgin Aggregate 0/2mm	Diorite			La Noubleau
Filler	Limestone			Omya

2.2 Mix design

A new type of base course mix (GB5® type) has been especially designed for the BioRePavation project using aggregate packing optimisation concept by maximizing their interlock [6]. The gradation of this mix is depicted on **Figure 2** and the percentage of each fraction is given in **Table 2**. 50% of RAP fractions are included. The 0-8 RAP fraction brought 0.704% of aged binder (AB) to final mix and the 8-12 RAP brought 0.986% of aged binder (AB) to the final mix. The nominal binder content (4.5%) has been determined after preliminary gyratory compaction tests. As a consequence, it was necessary to add 2.8% of fresh binder. Following this mix design, three asphalt mixtures have been prepared by adjusting the fresh binder content and composition based on each bio-material function (see Table 1) (MIX1, MIX2 and MIX3).

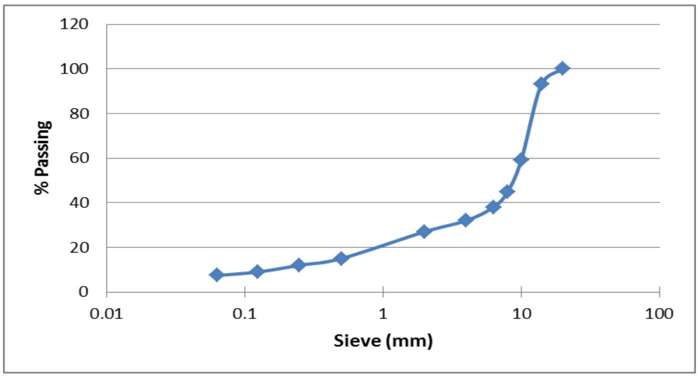

Figure 2. Aggregate gradation of the Bio-GB5 mix

Table 2. Mix design with 50%RAP

Fraction	10-14mm	0-2mm	Filler	8-12mm RAP	0-8mm RAP	Added Binder	
%	37.2	7.7	2.3	34	16	2.8	MIX1: 0.1%BM1+2.7%FB
							MIX2: 2.8%BM2
							MIX3: 0.1%BM3+2.7%FB

2.3 Binder blend compositions

In order to measure binder blends properties, assuming full blending of the bio-materials with the AB in the asphalt mixture, the binder blending proportions have been worked out and simulated in lab. Hence, materials BM 1 to 3, AB and FB were mixed together using the following proportions:

(FB+AB) = 62.36% of FB + 37.64% of AB

Binder related to MIX1: (BM1+FB+AB) = 2.26% of BM1 + 60.10% of FB+ 37.64% of AB

Binder related to MIX2: (BM2+AB) = 62.36% of BM2 + 37.64% of AB

Binder related to MIX3: (BM3+FB+AB) = 3.0% of BM3+ 59.4% of FB+ 37.64% of AB

3. EVALUATION AT BINDER SCALE

The characterization, using EU and US specification systems, of all organic materials, is shown in Table 3. It can be observed that AB is a highly aged binder, stiff and brittle, with a low penetration value at 25 °C, a very high Fraass breaking point temperature, a high DSR high critical temperature and a BBR critical temperature above 0°C. This fact confirms the need for rejuvenation in order to be able to reuse this RA in high contents in new asphalt mixtures.

Measurements on the blends produced in laboratory with BM 1 to 3, showed that the biomaterials restore the physical properties of the aged bitumen: penetration value increased, softening point temperature, DSR high temperature criteria decreased while Fraass and BBR critical temperature decreased. It is particularly interesting to note that BM2 provides a very soft blend in comparison to BM1 and BM3. Penetration is 80 1/10mm and DSR failure temperature is 61.5°C. Moreover, a strange effect is observed after the simulation of ageing in plant on BM2: the softening temperature and the DSR failure temperature decrease. This is certainly due to a decrease of the polymeric effect after oxidation. Finally, it is observed that EU and US systems give the same overall behavior in the high and low temperature domains, even if the levels of regeneration measured by both methods are not strictly comparable.

Table 3. Binder properties following EU specification system and US one

	EU binder specification				US binder specification						
					DSR failure temperature (°C)			BBR failure temperature (°C)			
Binders and blends	Penetration at 25°C (dmm)	Softening point (°C)	Softening point after RTFOT (°C)	Fraass breaking point (°C)	Original (25mm)	RTFOT aged (25mm)	PAV aged (8mm)	Low pass temp (m-value)	Low pass temp (S)	ΔTc (°C)	PG
AB	7	81.0		+14		99.4	36.5		> 0°		94 >-16
FB	55	49.0		-7	68.1	67.3	23.9	-12.6	-15.6	-3.0	64-22
FB+AB	25	61.8		+1	80.6	81.9	28.7	-7.5	-11.4	-3.9	76-16
BM1+FB+AB	33	57.2	61	-4	77.2	76.9	25.2	-12.1	-14.2	-2.1	76-22
BM2+AB	80	68.8	54.6	-7	79.6	61.5	19.5	-15.9	-15.3	0.6	58-22
BM3+FB+AB					71.9	73.8	24.7	-12.3	-14.5	-2.2	70-22

4. EVALUATION AT MIX SCALE

A first set of mixes has been manufactured using the European procedure using a French roller slab compactor (specimen geometry: 400*600*100mm). The compaction energy allows getting mixture with air void contents from 3 to 4.4%. EU tests have been carried out on these mixes and results are displayed in **Table 4**. MIX1 and MIX3 met the requirements for a conventional asphalt mix GB4 type (AC14 base) but MIX2 showed a lower fatigue resistance. It has to be noted that considering volumetric characteristics, moisture resistances and rutting performances, all mixes behave like an EME2. Concerning the lower fatigue results for MIX2, this is not consistent with binder finding as a soft elastomeric binder has been used as it was shown in **Table 3**. Complex modulus at 15 °C of MIX2 is also the highest whereas BM2+AB blend has the highest penetration value and the lowest high PG temperature. This might mean that BM2 evolves during the manufacturing process, changing its properties, or that a particular blending occurs between BM2 and the aged binder. Concerning MIX1 and MIX3, their modulus are in agreement with the PG temperatures and fatigue resistances are similar taking into account the accuracy of the measurement.

A second set of mixes was produced with a gyratory compactor following the US procedure (specimen geometry: 150 mm in diameter, 115±5 mm in height), targeting 4% air void content. Then, measurements, following the Superpave mixture design methodology, were carried out on this second set of mix. Results are displayed in **Table 5**. All mixes met the requirements for medium traffic level (10 to 30 million ESALs[1]). VMA and VFA exhibited conventional values whereas dust proportions reached the lower limit. Rutting and low temperature resistances were excellent. Particularly, the number of cycles to failure or at which tertiary flow begins appeared to be, for each mix, three times higher than the criteria. Concerning fatigue resistance, even if there is no Superpave criteria, K2[2] values are close to suggested values in literature. It has to been noted that these performance measurements (rutting, cracking and fatigue) do not allow discriminating between mixes taking into account measurement accuracies[3].

[1] Equivalent Standard Axle Load (80-kN) single-axle dual wheel loads
[2] K2 indicates the rate of damage accumulation
[3] ANOVA statistical analysis

Table 4. Performance of the using the European/French specification system

Mixes	Volumetric data		Water sensitivity % (NF EN 12697-12)	Rut depth at 30000 cycles (NF EN 12697-22+A1)	Complex modulus at 15°C, 10 Hz (NF EN 12697-26 - A)	Fatigue performance at 10°C, 25 Hz Strain needed to reach half of the initial modulus at 106 cycles (NF EN 12697-24 - A)
	Richness modulus	Void content after 100 gyrations (gyratory compactor) (NF EN 12697-31)				
Requirements for a EM2 (AC14 base)	> 3.5	<6%	>0.75	< 7.5 %	>14000 MPa	> 130 µdef
Requirements for a GB4 (AC14 base)		< 9%	>0.70	< 10%	>11000 MPa	>100 µdef
MIX1 (BM1+FB+AB)	3.0	4.2%	85%	5.6% (void = 4.4%)	12860 MPa (void = 3.2%)	ε6=113 µdef
MIX2 (BM2+AB)	3.0	3.0%	86%	4.3% (void = 3.5%)	14620 MPa (void = 3.0%)	ε6=84 µdef
MIX3 (BM3+FB+AB)	3.0	4.2%	90%	3.7% (Void = 5.5%)	12100 MPa (Void = 4.3%)	ε6=107 µdef

Both specification systems show that these innovative mixes met requirements. Rutting, cracking and moisture damage resistance were good. As expected, moduli were in the same order of magnitude while MIX2 showed, whatever the manufacturing procedure, a high stiffness whereas a very soft binder has been used.

Table 5. Performance of the innovative mixes using the US specification system

Mixes	Volumetric data					Stiffness (MPa) at 15°C , 10 Hz AASHTO TP-79	Rutting resistance (fow number) At 7% air void T=54°C AASHTO TP-79 (Cycles)	DCT (N / m) Low temperature cracking resistance At 7% air void At -12°C ASTM D7313	Fatigue life (four point bending mode) Fatigue line $N=K1*\varepsilon^{-K2}$ **AASHTO** T-321
	VMA	VFA	DP	%Va	%Gmm @ Nini				
Requirement medium traffic level	> 13.0	[65 – 78]	[0.6 – 1.2]	4	< 90.5		>190	>400	
MIX1 (BM1+FB+AB)	13.9	71.0	0.6	4	88.8	13002	609	625	K1=2e-7 K2=3.37 ε5=338 µdef
MIX2 (BM2+AB)	14.2	71.6	0.6	4	90.1	12213	578	581	K1=2e-8 K2=3.66 ε5=339 µdef
MIX3 (EMS+FB+AB)	14.2	71.8	0.6	4	87.9	11321	668	639	K1=6e-11 K2=4.47 ε5=393 µdef

In order to compare fatigue properties, the strain needed to reach 10^5 cycle lifetime (ε_5) has been calculated for US measurements[4]. Comparing to ε_6 from the EU approach, there are

[4] US fatigue measurements are performed in experimental conditions chosen to have life times between 1000 and 10000 cycles whereas EU measurements are between 10000 and 1000000 cycles.

no direct correlations. ε_5 appear to be similar for all mixes whereas ε_6 is strongly binder dependent. Different strain level ranges were used, around 100µdef for EU measurements and around 300µdef for US measurements. This difference induces certainly different damage modes inside the internal structure of the mixes and could explain why fatigue results are not comparable.

5. CONCLUSION

The lab study presented here shows that all alternative mixes from the BioRePavation project ensured excellent rutting resistance at high temperatures while providing superior fracture resistance at low temperatures and good fatigue life at intermediate temperatures. In other words, the three technologies help restoring the flexibility at low and intermediate temperatures while keeping very good rutting resistance. These results can be explained by the rejuvenating effect of the biomaterials as it has been demonstrated at the binder level measuring PG and consistency of the blends, before and after ageing.

Therefore, the main conclusion is that high amount of RA could be incorporated in hot mix asphalt along with appropriately selected additives/binders to reactivate the aged RA binder without compromising the performance of the mixture.

The next step, planned in the BioRePavation project, will be to perform a full scale experiment using an accelerated loading facility. It will provide information about fatigue resistance in real loading conditions. It will give opportunity to assess the relevance of fatigue tests in lab, especially for the non-conventional material and more generally to define links between lab and actual field.

6. ACKNOWLEGMENTS

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement n°607524. BioRePavation is co-funded by Funding Partners of The ERA-NET Plus Infravation and the European Commission.

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