Biobased Pavement: Lab Assessment of a Recycling Technique Without Petroleum Bitumen Addition in Irish Context

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Abstract. In the present paper, a lab technical study is proposed aiming at defining the recycling potential of Irish pavement materials using only a bio-material as added binder. The bio-binder used here is mainly made of a kraft paper industry residue, tall oil pitch by-products. It has been designed to replace totally conventional petroleum bitumen. In order to assess the applicability of this alternative solution, objectives are to understand: i) the rejuvenating effect of the bio-binder on the old bitumen, ii) the ageing behaviour of this particular blend, iii) the mechanical behavior of mixes made of reclaim asphalt and the bio-binder. This study shows, at lab scale, a very good ageing resistance of the bio-binder blended with old bitumen and good performances of the corresponding mixes. Hence, it is possible to recycle pavement materials without adding petroleum bitumen. The bio-binder used here could be used in the context of Irish pavement construction expecting a materials durability at least as good as conventional materials and a reduced carbon footprint.

Keywords: Bio-binder · recycling · Reclaimed Asphalt · rheology · pavement · sustainability

1 Introduction

There is growing pressure on the road industry to reduce its environmental impact. Utilization of materials from renewable biomass in asphalt production while increasing pavement recycling rate could present radical opportunities to reduce its negative impact on the environment. In this context, using a bio-binder as an alternative to petroleum bitumen could reduce the carbon footprint by storing renewable carbon for a long time.

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Meanwhile, increasing the use of reclaimed asphalt pavement (RAP) is a practical way to reduce fresh bitumen addition by taking advantage of the old remaining bitumen. It has already been proved, using a full scale accelerated tested, that it is possible to use a bio-binder in recycling technic [1]. The environmental benefit has also been assessed helped by a Life Cycle Analysis [2].

The general objective of the present study is to confirm that it is possible, in Irish context, to recycle old bituminous pavement materials using a bio-bitumen as added binder. More precisely this paper is dedicated to rheological properties of reclaimed bitumen (from Irish road materials) blended with a bio-binder produced by Eiffage company, named "Biophalt" and also assessment of the corresponding mixes (Fig. 1).

Fig. 1. Kraft paper industry residue, the tall oil pitch.

A first study has been carried out at the binder scale. Reclaimed bitumen has been extracted from RAP and blended, following several blending rates, with the bio-binder but also with a conventional bitumen for comparison. Blend properties has been assessed through rheological measurements. A second study has been carried out at mix scale. Mix design has been performed following Irish technical guidelines, by using the bio-binder and Irish materials: a fresh 40/60 petroleum bitumen, RAP and fresh aggregates. Three mixes have been designed. One with conventional bitumen and 30% of RAP, and two others with only the bio-binder incorporating respectively 30% and 40% of RAP.

2 Materials and Methods

2.1 Material

RAP 0/10, aggregates 10/20, 10/14, 6/10, 4/6, sand 0/4 and limestone filler were kindly provided by Breedon Group from the Rossmore-Lagan quarry, Binders used in this study and their properties are listed in Table 1. RA extraction procedure consist in the solubilization of bitumen from RAP in tetrachloroethylene followed by a distillation process in order to separate the old bitumen from the solvent.

2.2 Binder Blending and Ageing Procedure

The mass proportions of the bituminous blends are chosen according to mixture designs (see Sect. 2.4). Three binder blends are carried out accordingly (see Table 2). There are named: RAP32/REF68, RAP32/BIO68 and RAP47/BIO53. Blends are produced

Table 1. Naming and properties of studied binders

Sample number (réf. UGE)	Reference for the present paper	Material description	Penetration grade (1/10 mm) NF-EN-1426	Ring & Ball softening point (°C) NF-EN-1427
22026	RA	Reclaimed asphalt (4.97% of the RAP)	14	68.8
22048	BIO	Bio-binder Biophalt	158	73.2
22049	REF	Irish bitumen – 40/60 grade	55	52.6

by stirring at 130 °C for 15 min. Short (RTFOT) and long term (PAV) aging in lab is performed on blends according respectively to the standard NF EN 12607-1 and NF EN 14769.

Table 2. Blend proportion and ageing

Blend proportions	No ageing	RTFOT	RTFOT + PAV
RAP(47,5%)/BIO(52,5%)	RAP47/BIO53	/	/
RAP(31,8%)/BIO(68,1%)	RAP32/BIO68	RAP32/BIO68 - RTFOT	RAP32/BIO68 – RTFOT + PAV
RAP(31,1%)/REF(68,9%)	RAP32/REF68	RAP32/REF68 - RTFOT	RAP32/REF68 – RTFOT + PAV

2.3 Binder Rheological Measurement

Metravib device was used to characterize binder linear viscoelastic properties at seven frequencies, ranging from 1 to 80 Hz, at nine temperatures, varying from − 15 to 60 °C, in displacement control mode. The complex modulus test was conducted in tension-compression mode (E*) at low temperatures, from − 15 to 20 °C, and annular shear mode (G*) from 20 to 60 °C. The conversion from |G*| to |E*| is made assuming a Poisson's ratio of 0.5.

2.4 Mix Design

AC 20 dense bin 40/60 were targeted following Irish specifications [3]. Two recycling rates are considered: 30 and 40%. The composition of each mix is detailed in Table 4 (Table 3).

Table 3. Mix composition; En023-008 corresponds to aged EN022-295

	ENo22-166	ENo22-216	ENo22-295	ENo23-008 (Rilem)
Gravel 10/20 - Rossmore	22,2%	22,2%	22,0%	22,0%
Gravel 10/14 - Rossmore	10,0%	10,0%	10,0%	10,0%
Gravel 6/10 - Rossmore	10,0%	10,0%	10,0%	10,0%
Sand 0/4 - Rossmore	23,5%	23,5%	14,8%	14,8%
Limestone Filler - Rossmore	1,0%	1,0%	1,0%	1,0%
RAP 0/14 - Rossmore	30,0%	30,0%	40,0%	40,0%
REF	3,3%	0,0%	0,0%	0,0%
BIO	0,0%	3,3%	2,2%	2,2%
Total binder content	4,8%	4,8%	4,2%	4,2%

Mix made of 40% RAP and Biophalt as added binder has been subject to lab ageing following the RILEM protocol (4h at 135 °C and 5 days at 85 °C) [4]. These 4 mixes were evaluated according to the following tests: Compactibility (EN 12697-31) at 180 °C for the mix with bitumen 40/60 and 140 °C in case of mixes with the bio-binder; Water sensitivity (EN 12697–12 - Method A); Rutting test (EN 12697-22, – Large-size device) and Complex modulus tests (EN 12697–26, Annex C).

3 Results

3.1 Binder Properties

Figure 2 shows isochrones of complex modulus and phase angle for the RAP, REF, and BIO binders, for a loading frequency of 1Hz I. The bitumen recovered from reclaimed asphalt pavement shows the highest stiffness. Biophalt is less rigid in comparison to the others. The stiffness of the REF is somewhere between both binders. It means that a blend of Biophalt and RAP with appropriate proportions, could reach Irish bitumen stiffness level. Isochrones of complex modulus and phase angle, for binder blends before and after aging are shown on Fig. 3 and 4. Before ageing, RAP32/REF68 is largely stiffer than RAP32/BIO68 and RAP47/BIO53 (almost one decade above 40 °C). But it has to be noticed that there is tendency inversion regarding rheological properties of both type of blend, depending on the temperature. Indeed, above −5 °C, RAP32/REF68 is more elastic (higher phase angle) than RAP32/BIO68 and RAP47/BIO53 (as it can be seen on the Fig. 9) whereas the opposite behaviour is found below −5 °C. Some chemical species of the Biophalt appear to vitrify at relatively high temperature in comparison to conventional bitumen. Finally, phase angle curves show the effect of a polymeric network.

Indeed, above 25 °C phases angles stop to increase and remains around 70°. Even after ageing, blends with Biophalt remains softer than RAP32/REF68. But the main observation from these results is the outstanding stability of the blend incorporating Biophalt in comparison to the one with the reference bitumen, especially at high temperature. For both blends, stiffness increases and phase angle decreases with ageing (what is generally expected). But, for the blend incorporating Biophalt, there is an inversion of tendency above 25 °C. In this particular case, phase angle increases with ageing. This could be a consequence of the SBS polymer ageing (polymer networking effect decreases in this special case).

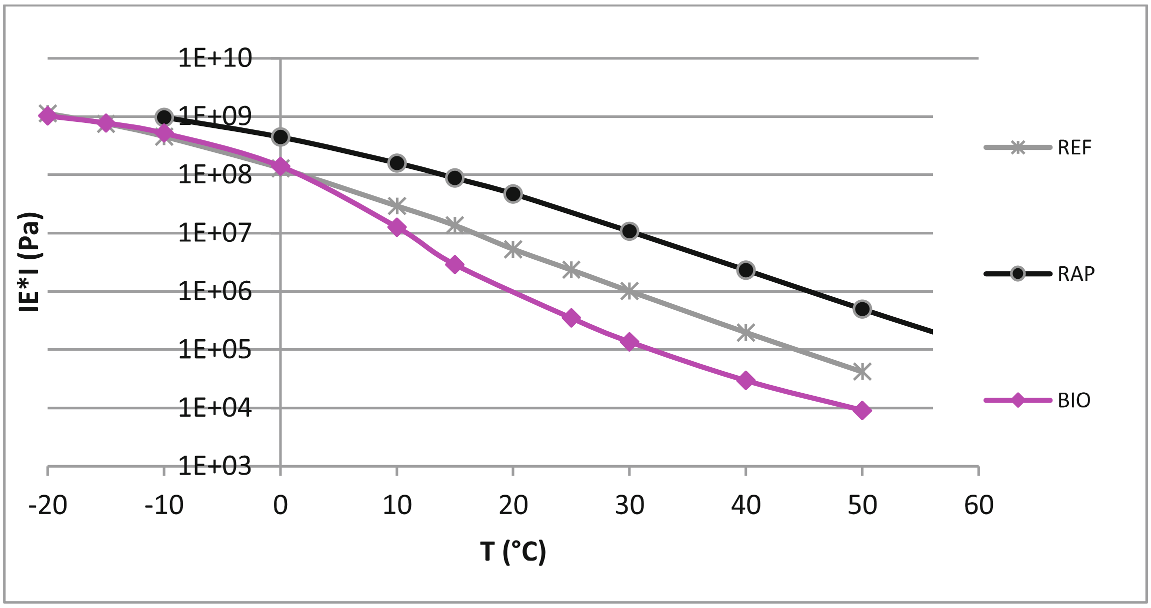

Fig. 2. Isochrones of complex modulus for binders

3.2 Mix Properties

Table 4 shows that ENo22–166, the reference mix with 30% RAP and 40/60 bitumen, meets the Irish specifications. EN022–216, the Biophalt equivalent mix is too soft and does not have the required mechanical properties. A solution, consisted in increasing the RAP content (and thus decreasing the quantity of Biophalt added) and adjusting slightly the grading curve, is successfully proposed: ENo22-295. ENo23-008 corresponds to EN022-295 aged according to the RILEM protocol (which have been designed to create RAP at lab scale). A stiffening effect is observed. This stiffening can be explained by an oxidized state of the binder. This mix behaves mechanically very well and suggests a further good recyclability. This last mix perform very well in comparison to the conventional mix. This result confirms what has been found at binder scale.

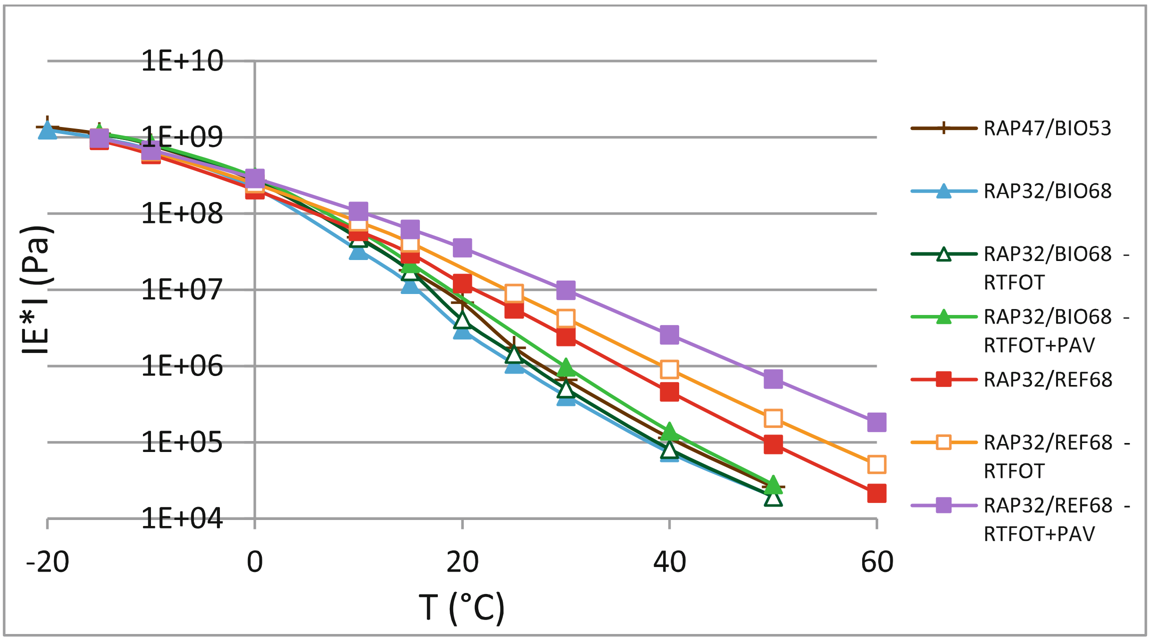

Fig. 3. Isochrones of complex modulus for binders

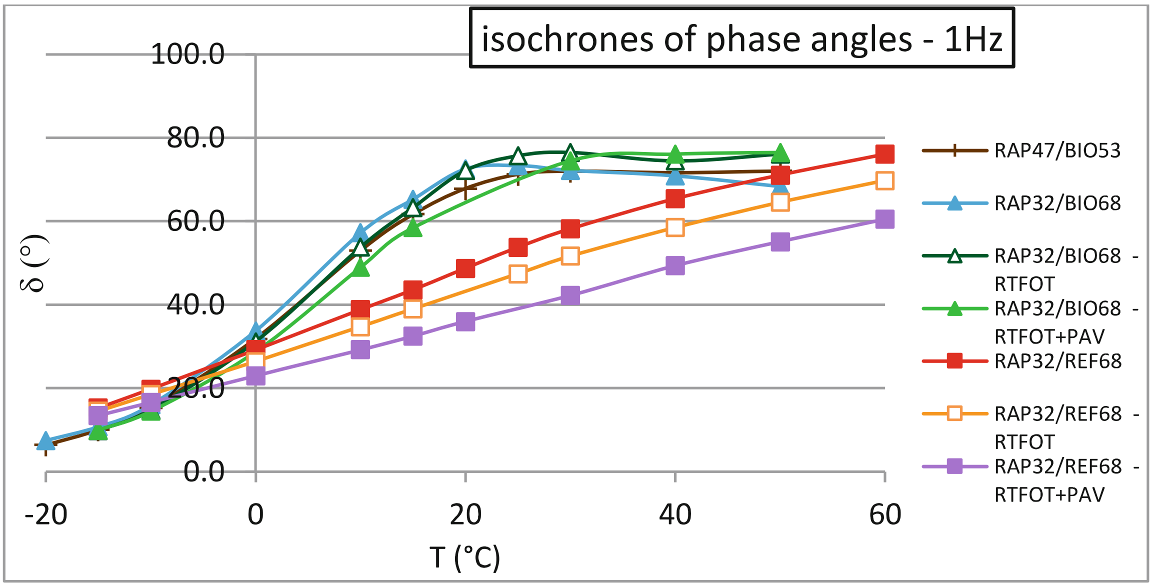

Fig. 4. Isochrones of phase angles for binders

Table 4. Mix properties

	AC 20 dense bin 40/60 spec	ENo22-166	ENo22-216	ENo22-295	ENo23-008 (Rilem)
MVRe (Mg/m3)		2.508	2.519	2.535	2.535

(continued)

Table 4. (*continued*)

	AC 20 dense bin 40/60 spec	ENo22-166	ENo22-216	ENo22-295	ENo23-008 (Rilem)
GPC V40g (%)	Vmin4,0 - Vmax7,0	4.7	4.2	5.3	6.9
Resistance to permanent deformation	WTSAir1,0 PRDAir9,0	WTSAir 0.08 PRDAir 3.3	Not measured	WTSAir 0.08 PRDAir 4.5	Not measured
	PLD 30 000 (%)	6.5	>>15	3.7	2.6
Water sensitivity	ITSd (kPa)	3 375	1 945	2 393	3 126
	ITSR70	91	89	85	81
Stiffness	E* - IT/CY 20 °C/124 ms (MPa)	6 500	Not measured	8 400	16 900

4 Conclusion

The possibility to recycle an old bituminous mix from Ireland using only a bio-binder as virgin bitumen has been assessed here. Linear viscoelastic properties of all binders show the high ageing state of the recovered binder and the particular rheological behaviour of the BIOPHALT which contains a strong polymer network.

Short (RTFOT) and long term (PAV) ageing has been applied on blends composed of: firstly, the recovered binder and the reference bitumen, secondly the recovered bitumen and the BIOPHALT. Blending proportions have been chosen according to the mix design. At high temperature measurements, above -5 °C, blend with BIOPHALT shows a very good resistance to ageing in comparison with the conventional blend. Below -5 °C, the opposite evolution is found regarding stiffness while phase angle of blend with BIOPHALT remains constant after ageing. Concerning mix performances, the present study show that it is necessary to add at less 40% of RAP in order to balance the softening effect of the bio-binder used here (BIOPHALT). Mix made of 40% of RAP and including only the BIOPHALT as added binder, performed very well considering the European specification framework.

Next step will be to build a test section with the materials assessed at lab scale and finally to monitor the evolution under traffic.

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