Effects of Ageing on Warm Mix Asphalts with High Rates of Reclaimed Asphalt Pavement

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Abstract Within the framework of the European Project SUP&R ITN a PhD thesis is carried out to study the durability of the combination of high rates of reclaimed asphalt pavement and warm mix asphalt technologies. For this purpose the complex modulus and fatigue resistance of three different asphalt mixtures, including surfactant modified and foamed warm mix asphalts, combined with reclaimed asphalt pavement (RAP) has been studied. The extra value is given by the application of an ageing procedure based on the oxidation of compacted materials in laboratory. It follows the recommendations of the RILEM TC-ATB TG5, which distinguishes between short and long term ageing. Fourier Transform InfraRed (FTIR) tests were carried out on the extracted bitumens to quantify the oxidation levels. An increase of the norm and a decrease of the phase angle of |E*| at 15°C 10Hz with ageing and RAP addition are experienced for all the mixtures. Similar to what happens with the slopes of the fatigue laws that tend as well to increase. A consistent correlation is observed between these evolutions and the evolution of the carbonyl index calculated. This reflects a trend towards more brittle materials with predicted fatigue live improved for low strain levels but reduced for high strain levels. In general, the tendency is similar for all procedures, so the use of warm technologies combined with high RAP amounts may need to be considered.

Keywords Ageing, Warm mix asphalt, Reclaimed asphalt pavement.

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1 Introduction

The combination of warm mix asphalt (WMA) and reclaimed asphalt pavements (RAP) is not a new concept, but this coupling seems challenging in order to favour a greener and more sustainable production of asphalt mixtures.

Separately, both procedures have their own advantages and drawbacks, but it is durability what concerns its performance during service life. Thus, very few is known about the changes in properties induced by the chemical ageing of these materials on-site.

Subsequently, the present study is based on the comparison of two different warm mix asphalt techniques, surfactant additive and foamed procedure, with a reference hot mix asphalt (HMA), when adding high rates of RAP (50%). The ageing protocol followed has been adapted from the RILEM TC-ATB TG5, consisting in two separate ageing steps, short term and long term ageing. The first one simulates the transport and layout of the mix during construction while the second is expected to reproduce service life evolution.

This research work is focused on the comparison of the mechanical performance through complex modulus and fatigue testing, coupled with the bitumen FTIR ageing evolution.

2 Methodology

Four different phases can define the methodology followed. The first three are related to laboratory works, materials characterization, mixtures production and performance of the ageing protocol, while the last phase focuses on testing.

The mixture chosen for the study has been asphalt concrete AC10 commonly used in road construction. This selection was made with the aim of reproducing the same formula of the reclaimed material, which came from the milling of an originally AC10 placed in the fatigue carousel at IFSTTAR Nantes, France (LCPC 2007). Thus, virgin gneiss aggregates were employed both for the coarse and fine fractions (0/2, 2/6 and 6/10 mm) in all mixtures.

RAP incorporation was previously prepared by splitting in 4 fractions the material for then being recomposed in order to assure the same granulometry in all mixtures, with and without RAP (Lopes et al. 2014).

Furthermore, 35/50 bitumen, the same as the original AC10 mixture, was employed, with a penetration grade and softening point of 37 (1/10 mm) and 52.8°C respectively. For the WMA, the first one was modified by adding 0.5% of CECABASE RT® surfactant to the virgin 35/50 bitumen, while the foaming process consisted in injecting 1.5% of water under pressure into the hot bitumen pipe before its introduction into the mixer.

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All mixtures were manufacture using a mlpc BBMAX 80 mixer during 75 seconds of mixing, 15 seconds of aggregates and fines homogenization (and RAP when used) plus 60 seconds of mixing when bitumen was added. RAP aggregates were preheated at 110°C during 2h before manufacture and virgin aggregates at different temperatures depending on the mixture, as it is summarized in Table 1. Figure 1 shows the methodology followed during the study.

Table 1 Denomination and manufacture temperature of the studied mixtures

Mixture	Denomination	%RAP	Ageing	Aggregates (°C)	RAP (°)	Manufacture (°C)
Hot Mix Asphalt	HMA0	0		160	-	160
	HMA0a	0	×			
	HMA50	50		210	110	160
	HMA50a	50	×			
Warm Mix Asphalt with Surfactant	WMA0	0		130	-	130
	WMA0a	0	×			
	WMA50	50		150	110	130
	WMA50a	50	×			
Foamed Warm Mix Asphalt	FWMA0	0		130	-	130
	FWMA0a	0	×			
	FWMA50	50		150	110	130
	FWMA50a	50	×			

Bitumen always at 160°C

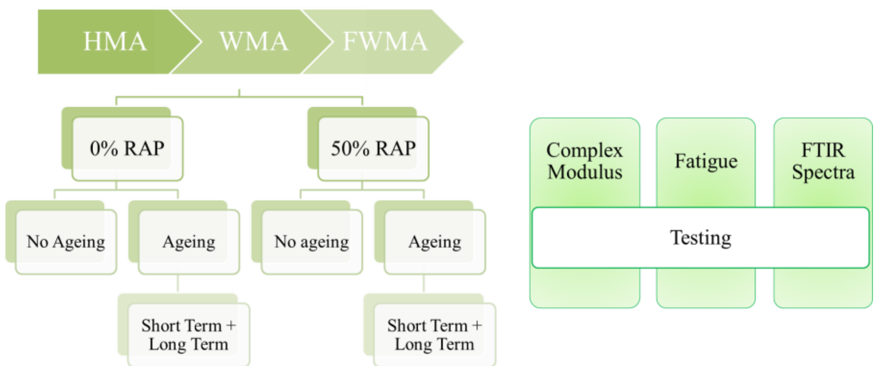

Fig. 1 Mixtures manufactured and tests performed

Once the mixtures were manufactured, the ageing phase on the selected ones could take place. The procedure has been adapted from the ageing protocol in laboratory of the RILEM Technical Committee ATB TG5 (De La Roche et al. 2013). The two differentiated phases, short term and long term ageing consisting in the oxidative thermal ageing of the asphalt mixture.

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The short term ageing involved maintaining the loose mix after manufacture during 4h at 135°C. Then it was compacted for the long term ageing that lasted 9 days at 85°C, both steps in a ventilated oven.

Then, considering that the work is focused on durability, the dynamic test for complex modulus determination (EN 12697-26, Annex A) and the dynamic test for fatigue resistance (EN 12697-24, annex A) were carried out to assess the mechanical performance of the mixtures. Also, on the recovered bitumen from all mixtures by the rotary evaporator for binder recovery (EN 12697-3), the Fourier transform infra-red spectroscopy (FTIR) was applied for ageing characterization.

From the Fourier Transform InfraRed (FTIR) test, only the carbonyl groups (esters, ketones etc.) represented by C=O double bond, were measured and calculated by the deconvolution method (Marsac et al. 2014) from the raw FTIR spectra. For the dynamic test for complex modulus four trapezoidal specimens were tested at temperatures from -10°C to 40°C and frequencies from 1 Hz to 40 Hz for the correct study of rheological and stiffness evolution of the samples.

Finally, fatigue testing was carried out by 2 point bending at 10°C, in strain control mode and at a frequency of 25 Hz. Trapezoidal samples were tested in three different strain amplitude levels, reaching fatigue life when the number of loading cycles decreased the specimen's initial stiffness modulus by 50%.

3 Analysis of Results

The results obtained for the different tests are summarized in Table 2, where the norm of the complex modulus and phase angle at 15°C 10 Hz of the mixtures, and the fatigue parameters are related to the ICo values from the FTIR spectra.

First of all, it should be noted the effect of ageing on the complex modulus results by increasing |E*| and decreasing the phase angle for every pair of mixtures. This even happens when RAP is added and aged. Independently the technique used on manufacturing, all mixtures perform over the 7,000 MPa requested on the standards.

If a regression line is traced for all the modulus values by their ICo, an increment of modulus $\Delta|E^*|$ = 460 MPa is observed for a ΔICo = 1. But when removing from the calculus de values for the FWMA50 mixtures, which are out of the tendency, this increment raises to $\Delta|E^*|$ = 580 MPa for ΔICo = 1. On the other hand, the phase angle tends perceived for all the samples is $\Delta\delta$ = -0.50, but when FWMA50 is not taken into account $\Delta\delta$ = -0.60 for ΔICo = 1. These trends reveal roughly the increase on modulus experienced by the mixtures when ageing occurs.

Then, for the fatigue of mixtures, the laws were fitted by log-linear regression of number of cycles by strain level. The parameter ε_6 representing the strain at 1,000,000 cycles was calculated, as well as the slope of the fatigue law (1/b). However, in order to compare all the mixtures, the value of ε_6 were corrected based on Moutier's approach for the same air voids content of 4.5%, using the

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formula $\Delta\varepsilon 6\,(\mu\text{def}) = 3.3\Delta C\,(\%)$ (Moutier 1991). The fatigue laws parameters evolution by the index carbonyl of the mixtures is discussed regarding Table 2.

Table 2 Results from FTIR, complex modulus and fatigue testing

Mixture	ICo (%)	Complex Modulus |E*| (MPa) 15°C 10 Hz	Phase Angle (°)	ε_6 Corrected (10^{-6} mm)	Fatigue Slope (1/b)
HMA0	1.80	12,497	15.0	115	-5.99
HMA0a	4.96	14,156	10.8	123	-8.35
HMA50	4.08	14,590	12.2	127	-7.08
HMA50a	8.27	15,847	11.3	122	-6.99
WMA0	1.46	12,498	14.6	100	-5.69
WMA0a	5.40	15,492	10.7	123	-7.68
WMA50	3.74	13,721	12.7	119	-5.55
WMA50a	8.39	16,035	11.0	108	-16.70
FWMA0	0.48	10,921	16.1	91	-2.79
FWMA0a	5.40	14,448	12.2	111	-9.00
FWMA50	5.47	13,122	14.0	105	-5.06
FWMA50a	10.35	15,460	11.5	113	-7.08

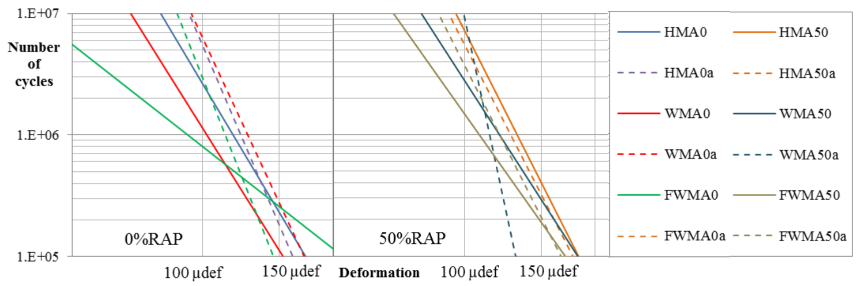

Fig. 2 Fatigue results for mixtures with 0% RAP and 50% RAP before and after ageing

The results obtained show an overall increase in the slope of the fatigue law when the ageing protocol is applied, as well as when RAP is added. When results from fatigue and complex modulus test are compared, the increased level of modulus seems to induce a more fragile response of the material translated by the slope increase. Particularly, a drastic increase of the slope is observed for the WMA50a mixture.

If fatigue laws are plotted in number of cycles by ε, the overall effect of ageing and RAP addition correspond to a clockwise rotation. Considering as rotation point, the value of ε where the curves cross, for the HMA mixtures the mix is going to perform better when aged for strain level ε<136µdef. However, the HMA with RAP suffers an overall decrease when ageing occurs.

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In the case of WMA mixtures, when ageing the surfactant mix is going to develop higher resistance in terms of ε_6 than the unaged mix. But for the 50% RAP mix over 111µdef, when ageing happens its behavior is going to decrease. Moreover, foaming samples perform better when ageing, this could be related to a comparatively moderate ageing during the manufacturing process as reflected by the low ICo level measured. The average ε values for the rotation points are respectively around 123µdef and 157µdef for 0% and 50% RAP mixtures.

4 Conclusions

The research presented in this paper was carried out as part of the Marie Curie Initial Training Network (ITN) action, FP7-PEOPLE-2013-ITN, with the fundings from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement number 607524.

The aim of this work was to compare the evolution of the mechanical performance of surfactant and foaming WMA technologies for temperature reduction, when also adding high rates of reclaimed materials. The durability study carried out led to the following conclusions:

- Regarding the effect of ageing observed, through the ICo, on the complex modulus and phase angle behavior, the level of stiffness increases, regardless of the technique used.
- In terms of fatigue resistance, the improvement observed for the ε_6 parameter when adding RAP is systematic. In the case of the slope, the evolution to a higher value happens both for ageing and RAP adding situations.
- Generally, the mechanical performance of the mixtures tends to improve, increasing their response against stresses independently of the manufacturing technique employed.

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