

Use of binder additives in different Warm Mix Asphalts

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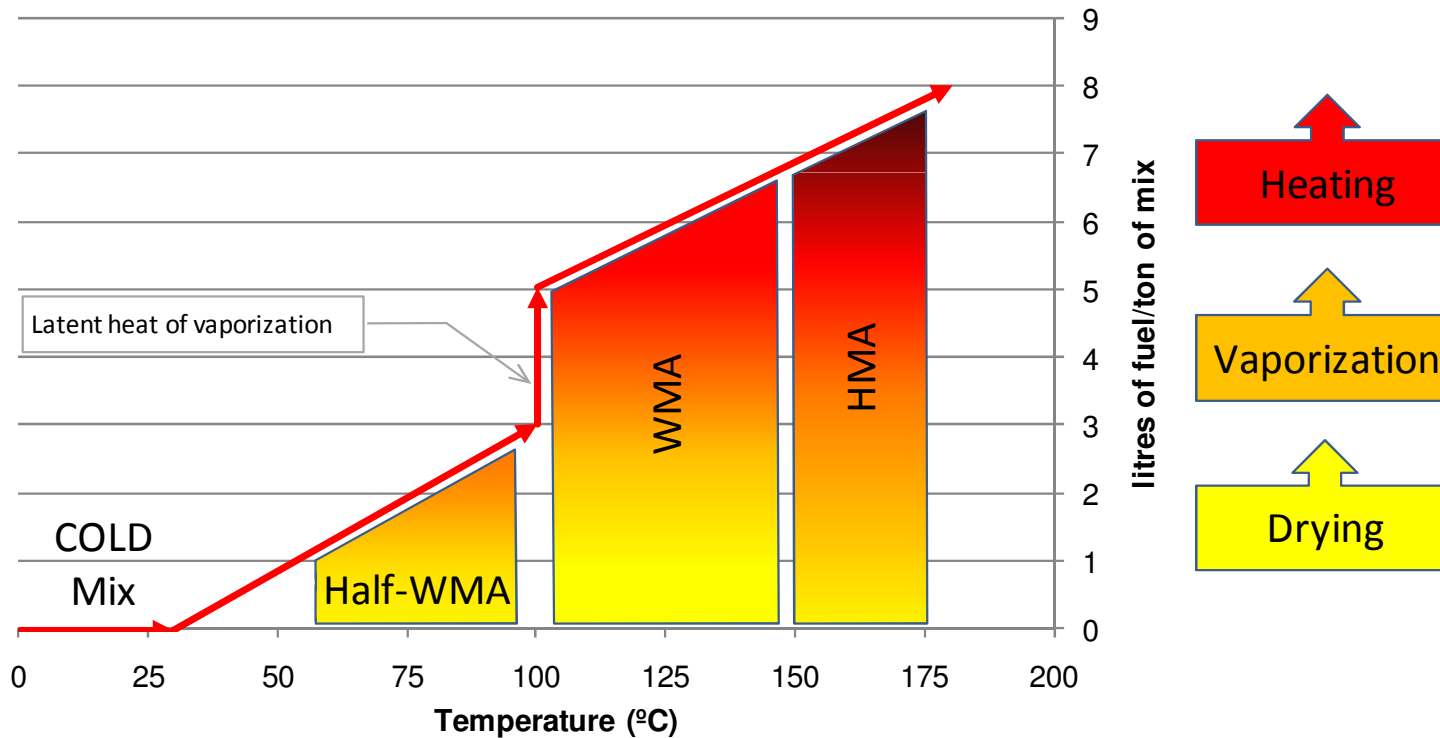


Introduction

- > Comparison between the engineering properties (laboratory) of a HMA and two WMA mixtures produced with a **F-T synthetic wax** or a **Surfactant**
- > Validation of laboratory results in a pavement trial built with those mixtures (produced in a plant)
- > Additional study (lab) of WMAs with less traditional blends of waxes and bitumens (hard and soft)
- > Additional study (lab) on the use of surfactants to reduce the production temperature of AR and recycled mixtures

Literature review on WMA mixtures

- > Several processes and products are available to produce WMA and half-WMA at lower temperatures





Literature review on WMA mixtures

> Lower plant mixing temperatures of WMAs mean

- Reduction in fuel consumption, emissions, odours and health problems
- Improved workability, longer haul distances and longer construction season
- Minimized hardening → improves fatigue resistance

> WMA technologies have some engineering challenges

- Minimized hardening → higher potential for rutting
- The relationships between engineering properties of WMAs and their field performance need to be investigated



CASE STUDY 1

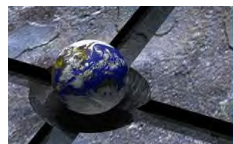
Comparative performance of conventional HMA and WMA mixtures (**lab results**)



Comparative performance of conventional HMA and WMA mixtures (lab results)

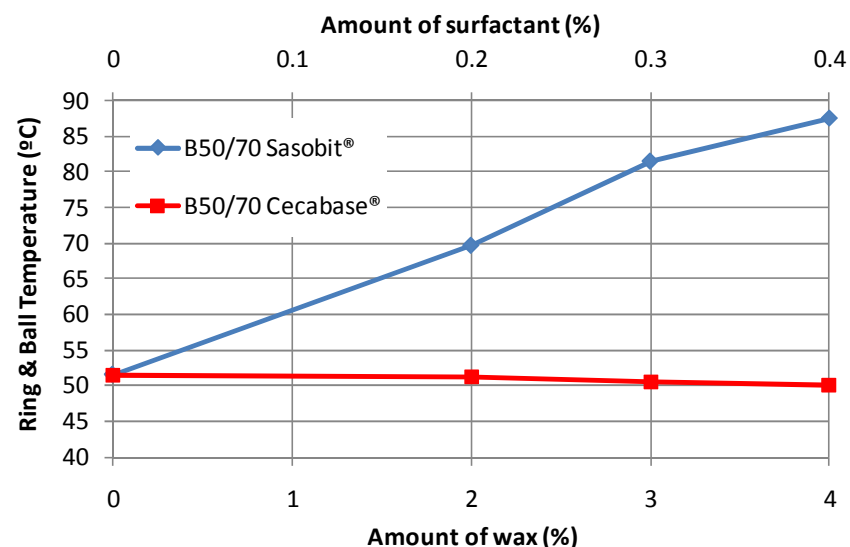
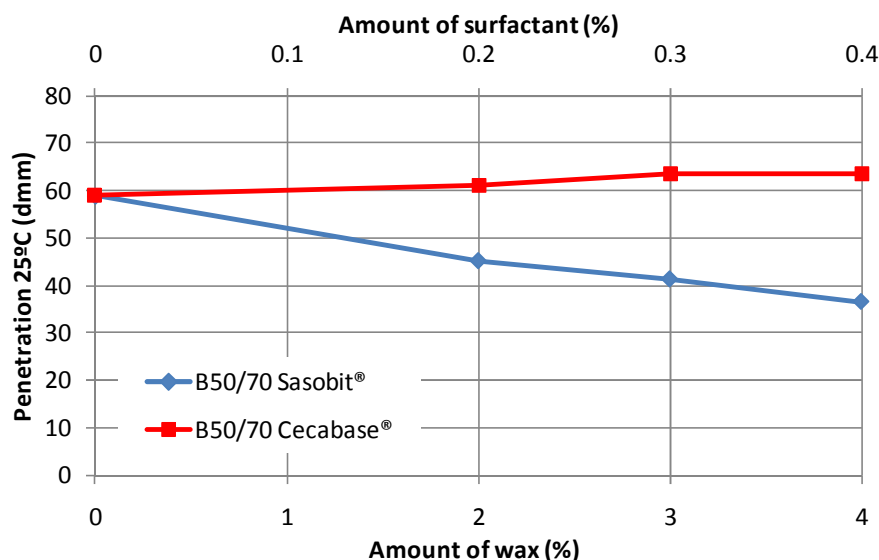
- > Several binders were characterised in order to establish the optimum additive content
 - Paving grade bitumen – B50/70
 - Additive 1: F-T Synthetic Wax – 2 to 4%
 - Additive 2: Surfactant – 0.2 to 0.4%

- > Tests performed in the study
 - Basic characterization (penetration, softening point)
 - Viscosity with rotating spindle apparatus
 - Rheology tests (DSR)



Comparative performance of conventional HMA and WMA mixtures (lab results)

> Basic characterization of binder

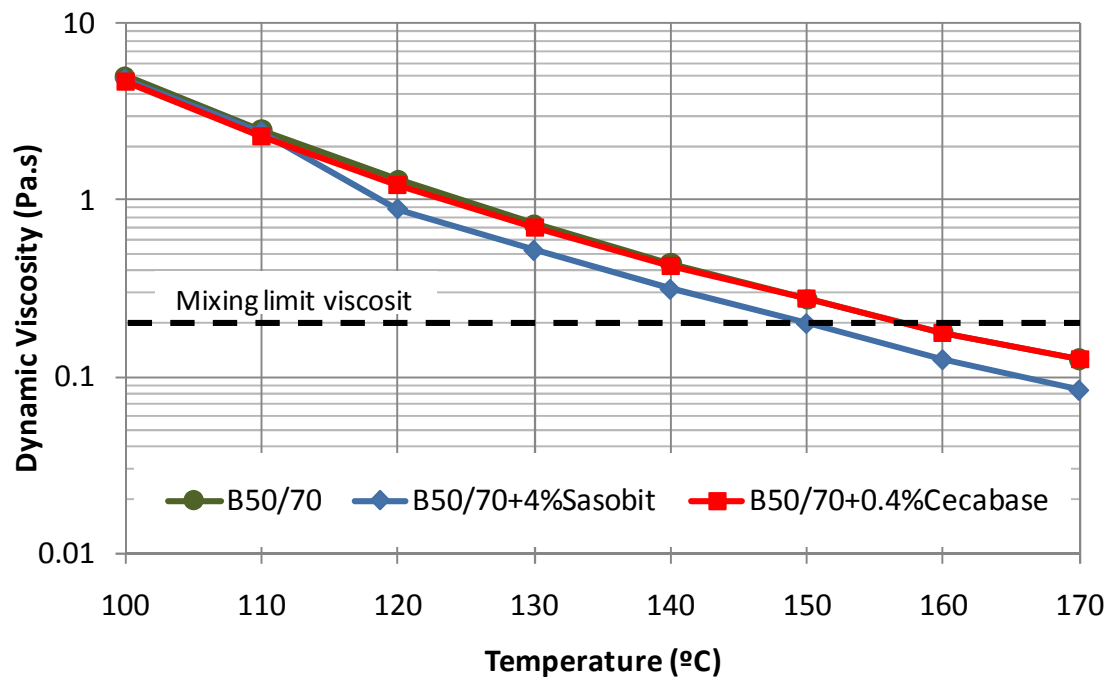


- > Surfactant barely changes binder basic properties
- > Wax has a significant effect (hardening of binder)



Comparative performance of conventional HMA and WMA mixtures (lab results)

- > Viscosity tests in the rotating spindle apparatus
 - Carried out at different temperatures (100 to 170 °C)



Mixing temperatures

> Synthetic wax
(reduction of 8 °C)

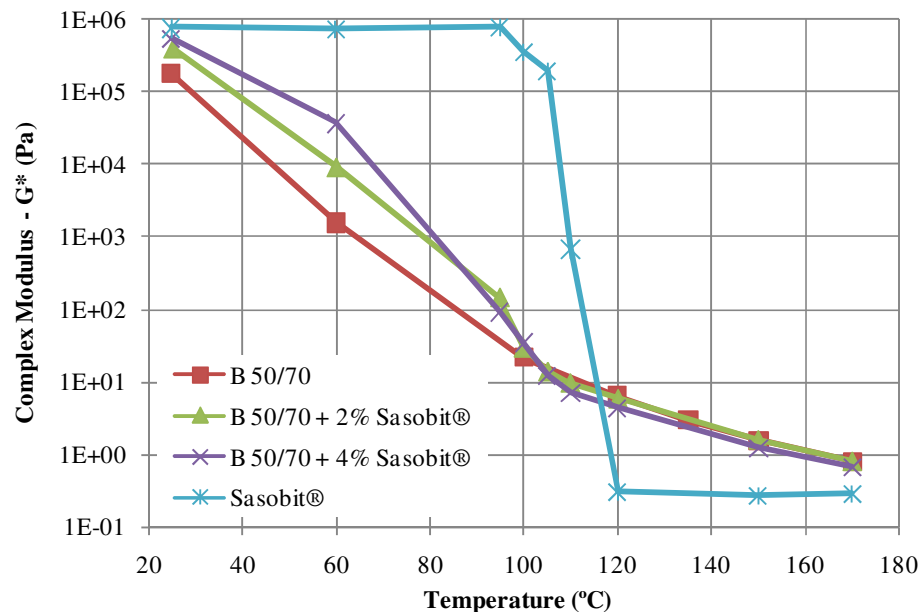
> Surfactant
(no reduction)



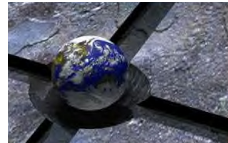
Comparative performance of conventional HMA and WMA mixtures (lab results)

> Rheology tests in the DSR

- 40 mm parallel plates, 1 mm gap, 25-170 °C, 0.1-10 Hz
- Carried out in bitumen, wax and 2 or 4% modified binders

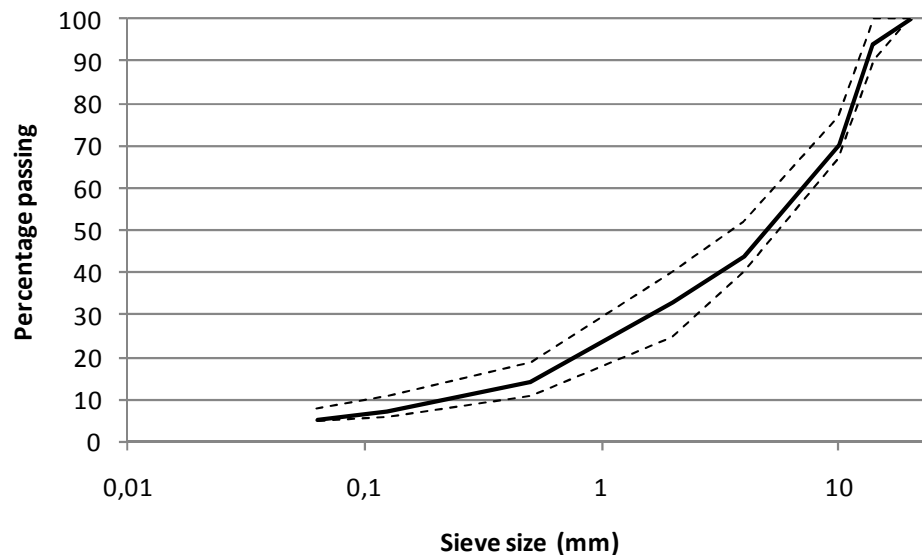


- > Wax additive increased G^* (elastic part) in proportion of the amount of additive used, mainly at 25 to 80 °C
- > A minor reduction of G^* was observed above 120 °C
 - Maximum amount of wax (4%) was used



Comparative performance of conventional HMA and WMA mixtures (lab results)

> Mix design was only carried out for the **HMA** control mixture (AC 14 Surf 50/70) → binder content 5.0%



Mix design validation

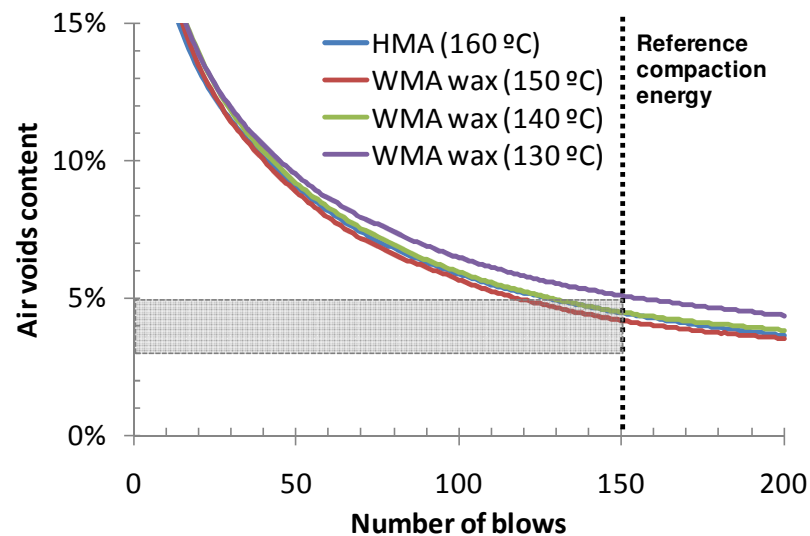
Binder Content (%)	4.5	5.0	5.5
WTS air (mm/10 ³)	0.06	0.08	0.09
ITSR (%)	39.9	42.1	41.9
Voids content (%)	4.4	3.5	2.7

Design grading curve of HMA and WMAs

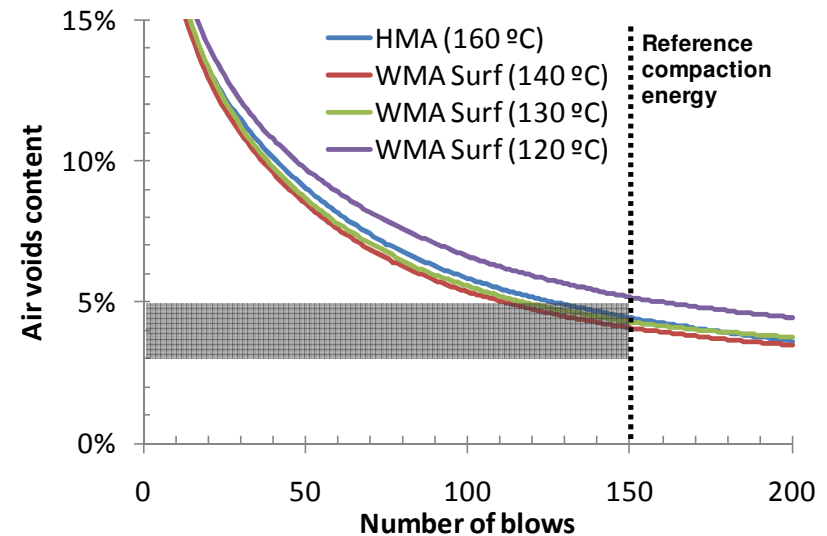


Comparative performance of conventional HMA and WMA mixtures (lab results)

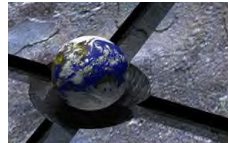
> Mixing/compaction temperatures were chosen by means of EN 12697-10 compactability test



- WMA with 4% wax + viscosity results (reduction of 15 °C)



- WMA with 0.3% surfactant (reduction of 30 °C)



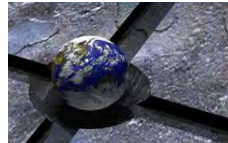
Comparative performance of conventional HMA and WMA mixtures (lab results)

> Composition, water sensitivity tests and WTT

Characteristics of the mixtures resulting from the laboratory study

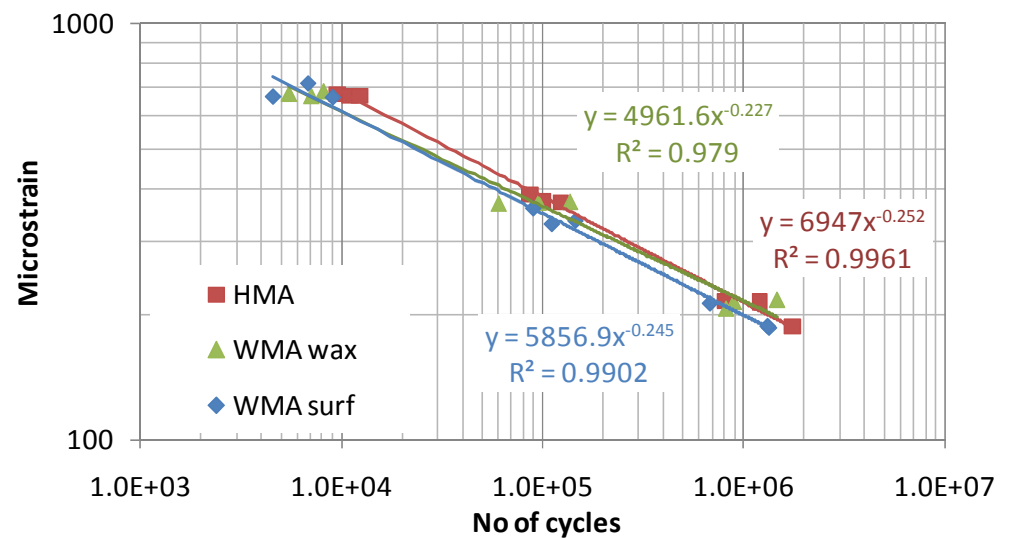
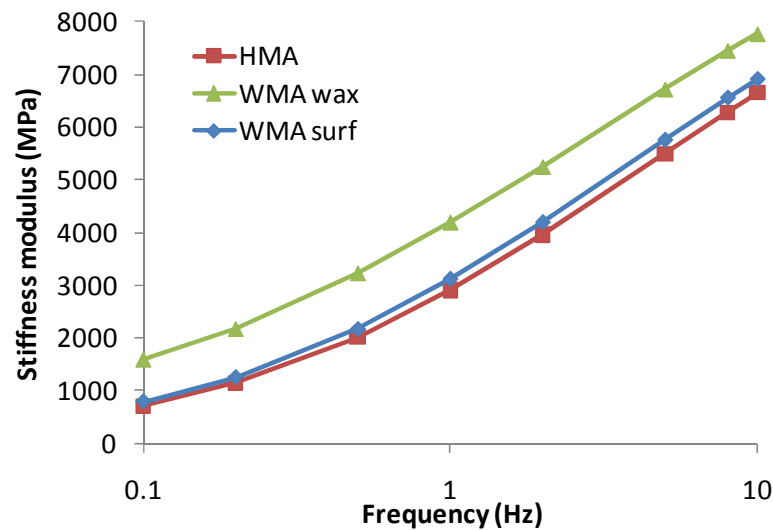
Mixture	Standard	HMA	WMA wax	WMA surf
Bitumen Content (%)	EN 12697-1	5.0	5.0	5.0
Voids content (%)	EN 12697-8	3.0	3.5	3.0
Max. deformation after 10000 cycles (mm)	EN 12697-22	2.7	2.1	2.6
WTS air (mm/10 ³)	EN 12697-22	0.08	0.10	0.11
ITSR (%)	EN 12697-12	47	42	52

- ITSR problem caused by the type of aggregate (syenites)
- WTT and compaction → good results (WMAs similar to HMA)

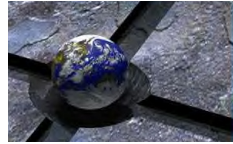


Comparative performance of conventional HMA and WMA mixtures (lab results)

> Stiffness modulus and fatigue cracking resistance



- Stiffness of WMA wax is higher (binder properties)
- Fatigue of WMAs and HMA is similar



CASE STUDY 1

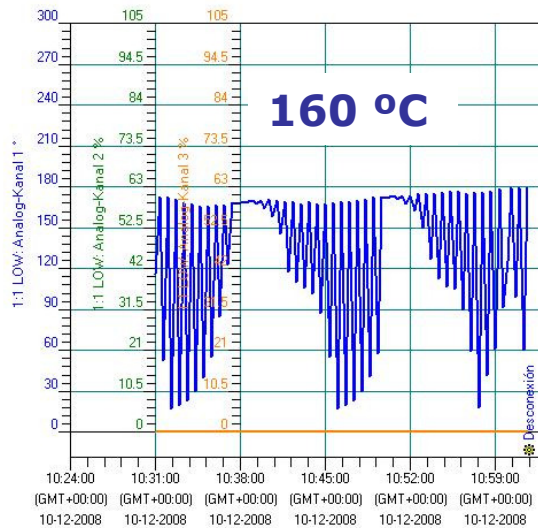
Comparative performance of conventional HMA
and WMA mixtures (**pavement trial results**)



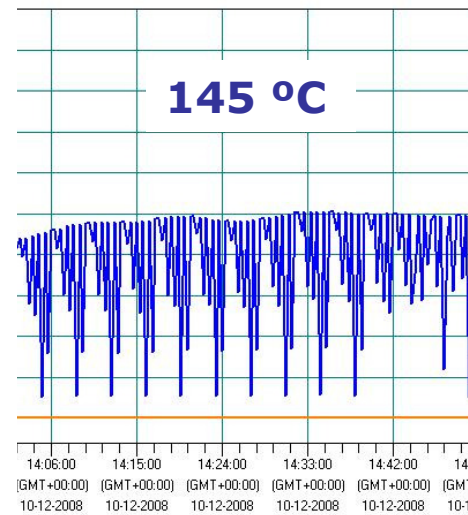
Comparative performance of conventional HMA and WMA mixtures (trial results)

> Production of mixtures in the asphalt plant

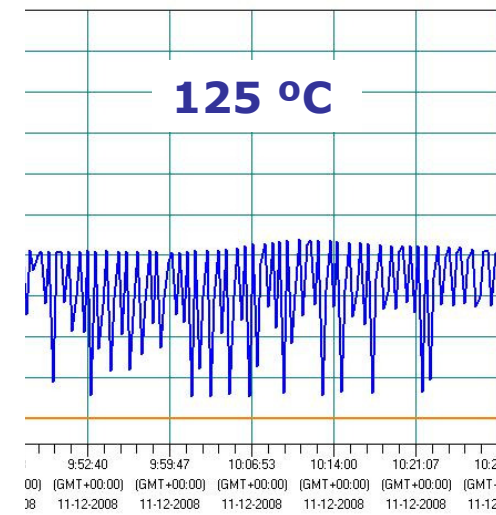
- Temperature of the mixes carefully controlled and recorded



a) HMA

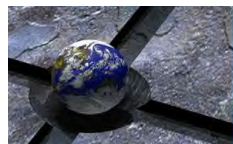


b) WMA wax



c) WMA surf

Temperature records obtained directly from the skip of the asphalt plant



Comparative performance of conventional HMA and WMA mixtures (trial results)

- > Better working conditions provided to the paving crew and the reduction of their exposition to fumes



a) HMA mixture



b) WMA mixture

Fumes observed during truck loading at the asphalt plant

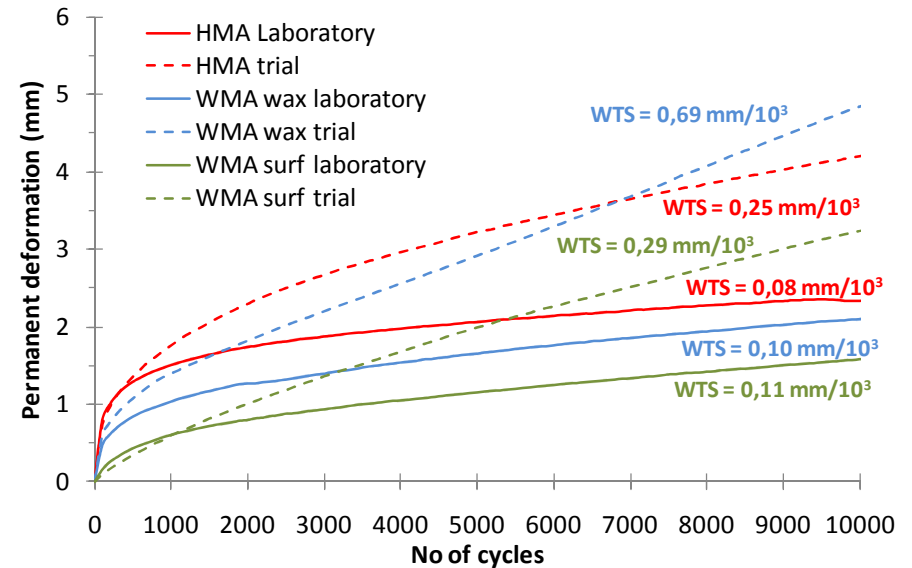


Comparative performance of conventional HMA and WMA mixtures (trial results)

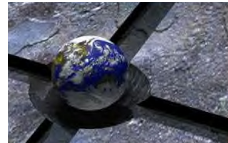
> Composition, water sensitivity tests and WTT

Characteristics of the trial mixtures

Mixture	EN Standard	HMA	WMA wax	WMA surf
Bitumen content (%)	12697-1	5.0	5.1	5.3
Voids content (%)	12697-8	2.4	2.1	3.4
ITSR (%)	12697-12	85.8	85.2	67.0



- Increase in ITSR values → Low voids content
- Great reduction in rutting resistance → Fuel contamination?



Comparative performance of conventional HMA and WMA mixtures (trial results)

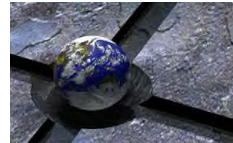
> Evaluation/Evidence of fuel contamination problem

WTT (EN 12697-22) results in laboratory and in the trial

Mixture		HMA	WMA wax	WMA surf
WTS air (mm/10 ³)	Lab initial results	0.08	0.10	0.11
	Trial results	0.25	0.69	0.29
	Slabs made in lab with bitumen collected in the plant	0.10	0.12	0.14

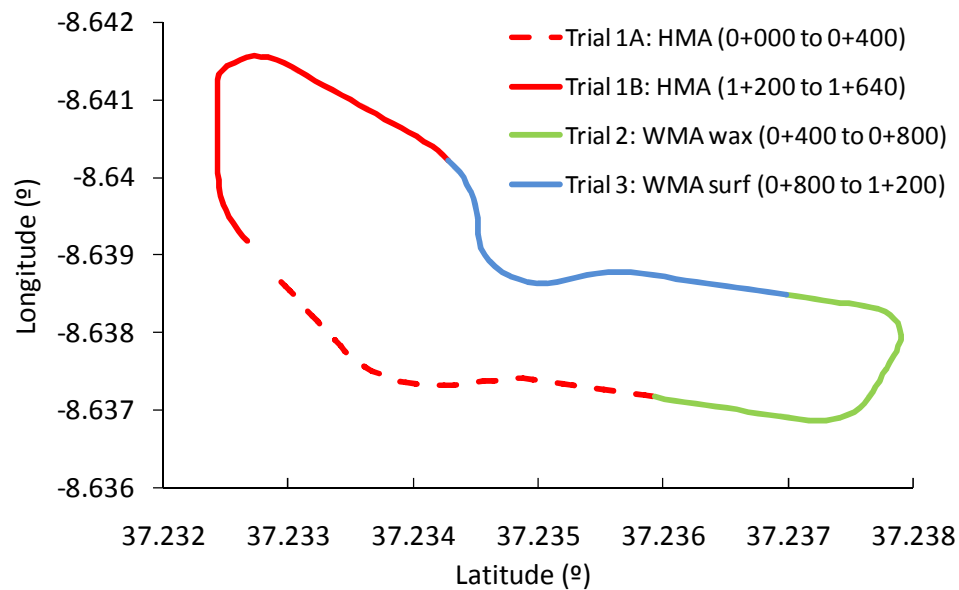
Binder properties before and after recovery (EN 12697-3)

Mixture			HMA	WMA wax	WMA surf
Penetration (0.1 mm)	EN 1426	Before recovery	52	33	51
		After recovery	47	58	61
Ring & Ball (°C)	EN 1427	Before recovery	50	88	48
		After recovery	53	52	48



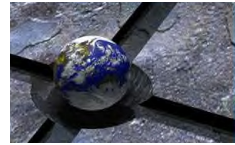
Comparative performance of conventional HMA and WMA mixtures (trial results)

> Structural characterization of pavement trial



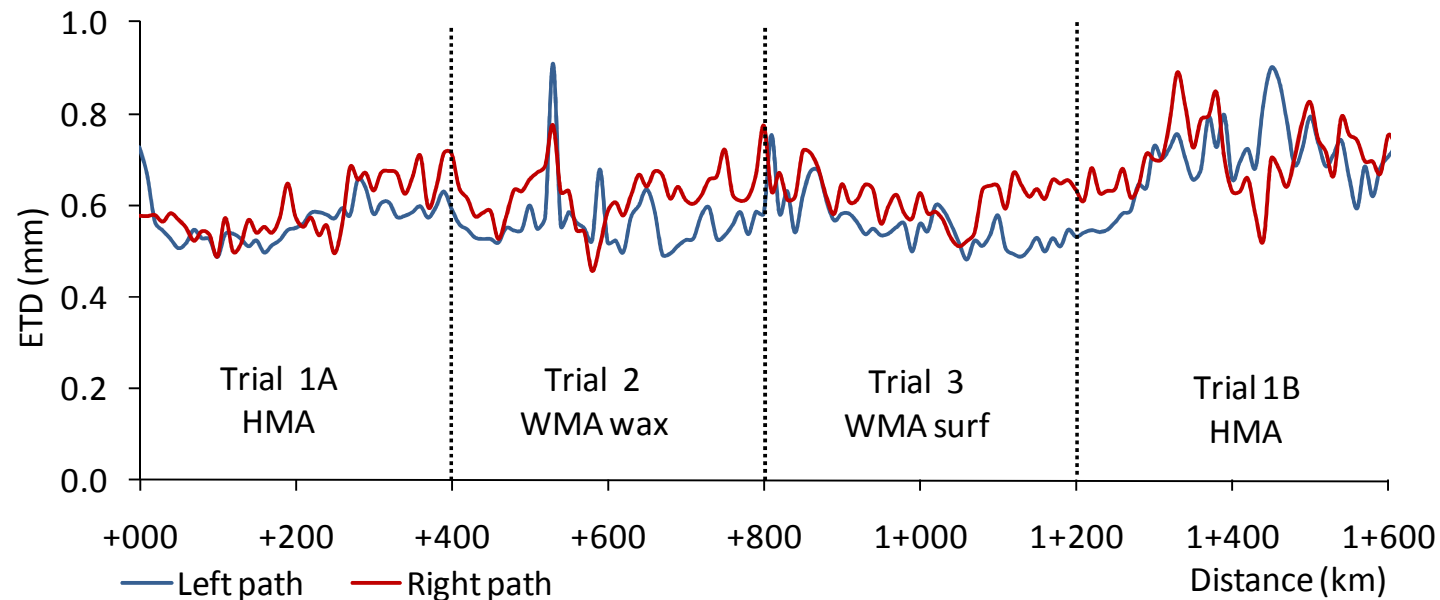
Trial	1A HMA	2 WMA wax	3 WMA surf	1B HMA
Maximum norm. deflection (before layer)	686	1088	804	1079
Maximum norm. deflection (after layer)	353	555	428	530
Ratio	51%	51%	53%	49%

- Similar structural contribution of all mixtures (HMA and WMAs) laid down in surface layer



Comparative performance of conventional HMA and WMA mixtures (trial results)

> Functional (texture) classification of pavement trial



- Similar texture was observed for all mixtures (HMA and WMAs) laid down in the surface layer of the pavement trial



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CASE STUDY 2

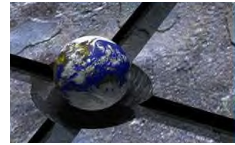
WMA mixtures produced with unconventional blends of wax with soft or hard bitumens





WMA mixtures produced with unconventional blends of wax with soft or hard bitumens

- > A high modulus bituminous mixture AC 20 Base (HMBM) and a high flexibility bituminous mixture AC 14 Surf (HFBM) were used in this study;
- > HMBM produced with B10/20 or B35/50 + wax;
- > HFBM produced with B50/70 or B160/220 + wax;
- > The same binder content (HMBM = 5.3%; HFBM = 5.0%), aggregate type and gradation were used for both HMA and WMA mixes.



WMA mixtures produced with unconventional blends of wax with soft or hard bitumens

> Basic properties of the binders

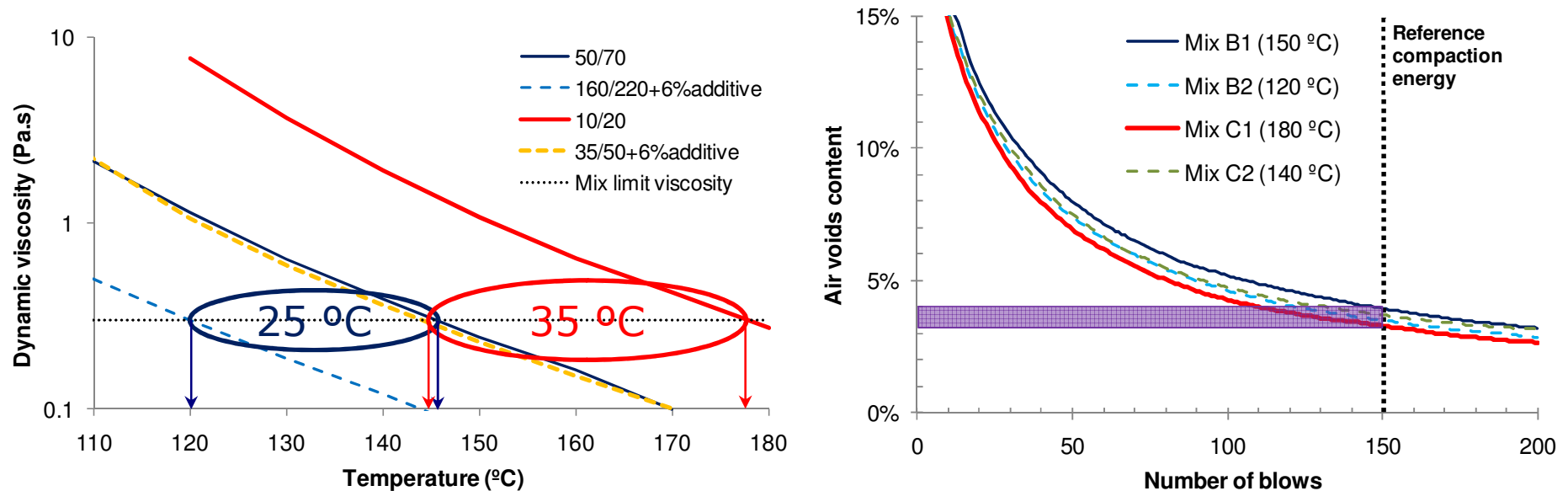
Mixture	Bitumen	Amount of additive	Pen (0.1 mm)	R&B (°C)
HMBM	10/20	0%	16.4	70
	35/50	0%	37.9	52
		2%	25.7	73
		4%	23.5	89
		6%	21.8	94
HFBM	50/70	0%	53.5	50
	160/220	0%	163.7	39
		2%	96.0	52
		4%	79.6	80
		6%	70.2	92

> 6% wax additive led to penetration values close to those of std binders and outperformed their R&B temperatures

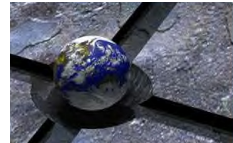


WMA mixtures produced with unconventional blends of wax with soft or hard bitumens

> Dynamic viscosity and compactability tests

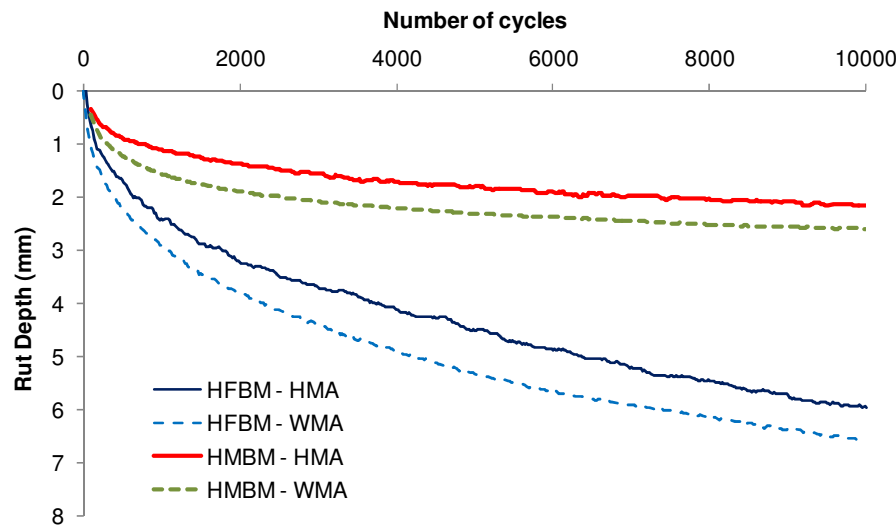


Compactability test results allowed to increase the temperature reductions obtained in the dynamic viscosity tests from 25 to **30°C** and from 35 to **40 °C**



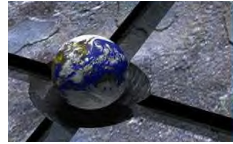
WMA mixtures produced with unconventional blends of wax with soft or hard bitumens

> Resistance to permanent deformation



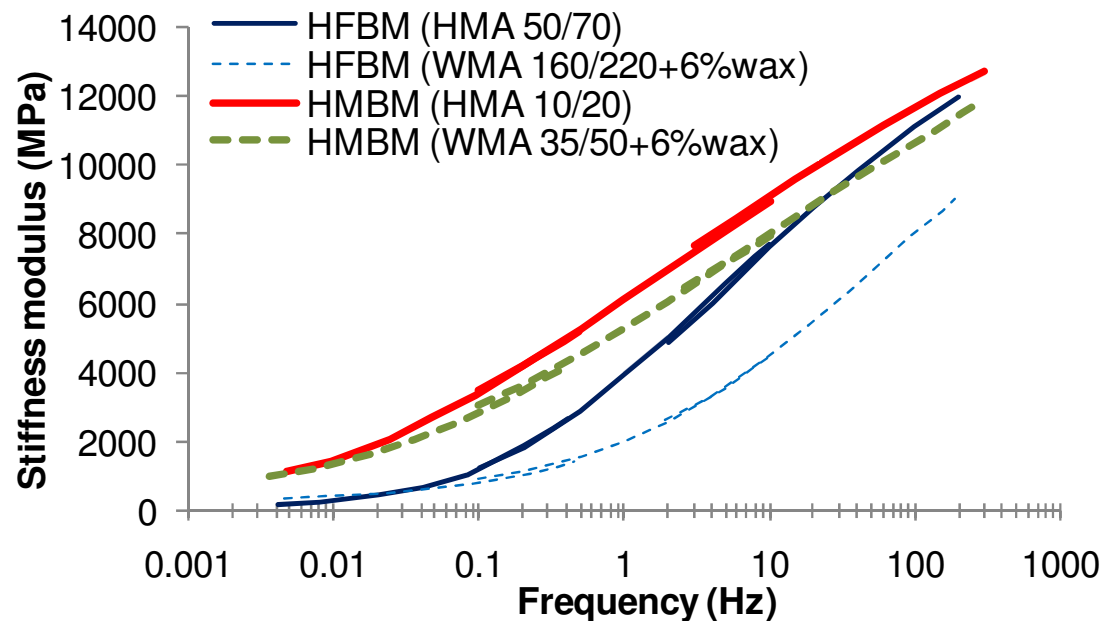
> WMA mixtures showed resistance to permanent deformation similar to that of HMA mixtures

Mixture	HFBM HMA 50/70	HFBM WMA 160/220+6%wax	HMBM HMA 10/20	HMBM WMA 35/50+6%wax
WTS_{AIR} (mm/10 ³ cycles)	0.24	0.25	0.07	0.06
PRD_{AIR} (%)	13.55	15.60	5.13	6.16
RD_{AIR} (mm)	5.70	6.59	2.16	2.60

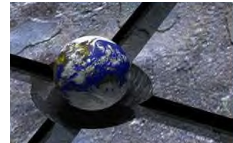


WMA mixtures produced with unconventional blends of wax with soft or hard bitumens

> Stiffness Moduli (10, 20 and 30 °C)

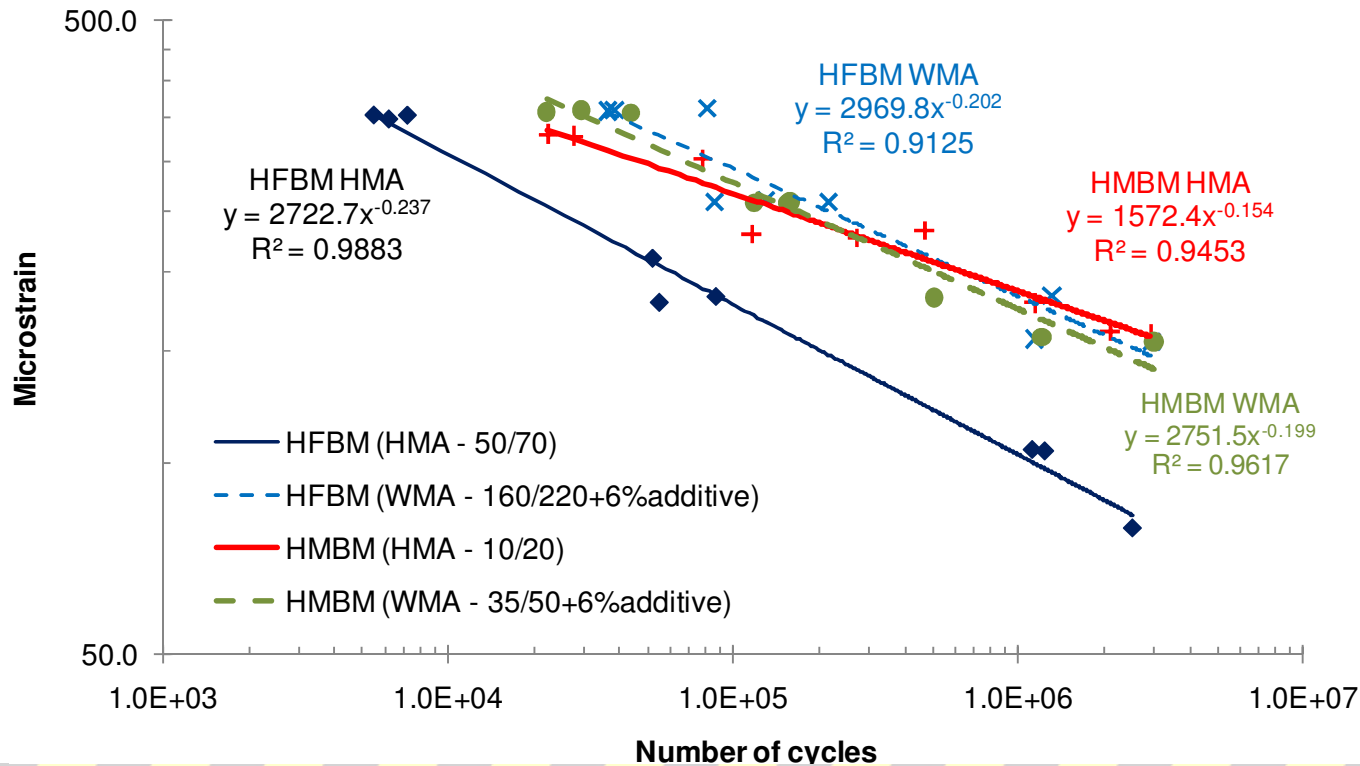


WMAs have lower stiffness moduli than HMAs, especially at lower temperatures



WMA mixtures produced with unconventional blends of wax with soft or hard bitumens

> Fatigue cracking resistance



HMBMs showed similar fatigue performance

HFBM WMA showed significantly higher fatigue resistance than HFBM HMA



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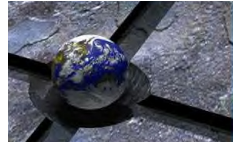
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CASE STUDY 3

Use of surfactants in recycled and asphalt rubber WMA mixtures





Use of surfactants in recycled and asphalt rubber WMA mixtures

- > A Hot Mix Recycled Asphalt (HMRA - AC 0/14), with 50% RAP, and an Asphalt rubber (AR-SMA), with 21% rubber, were studied;
- > Two mixtures were produced for each type (with and without surfactant additive) using a 50/70pen base bitumen;
- > The binder contents used were 5.2% and 9% (for HMRA and AR-SMA, respectively), by mass of mixture.



Use of surfactants in recycled and asphalt rubber WMA mixtures

> Penetration and softening point of studied binders

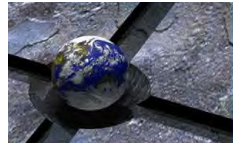
Mixture	Binder	% additive	Penetration (0.1mm)	R&B temperature (°C)
---	50/70	0.0	60.9	50.7
---	50/70	0.5	63.7	50.8
AR SMA-A	AR	0.0	25.6	76.2
AR SMA-B	AR	0.5	25.5	76.6
HMRA-A	Recycled*	0.0	18.1	68.0
HMRA-B	Recycled*	0.5	18.5	66.0

* this binder was recovered from the HMRA's using the centrifuge and the rotary evaporator apparatus



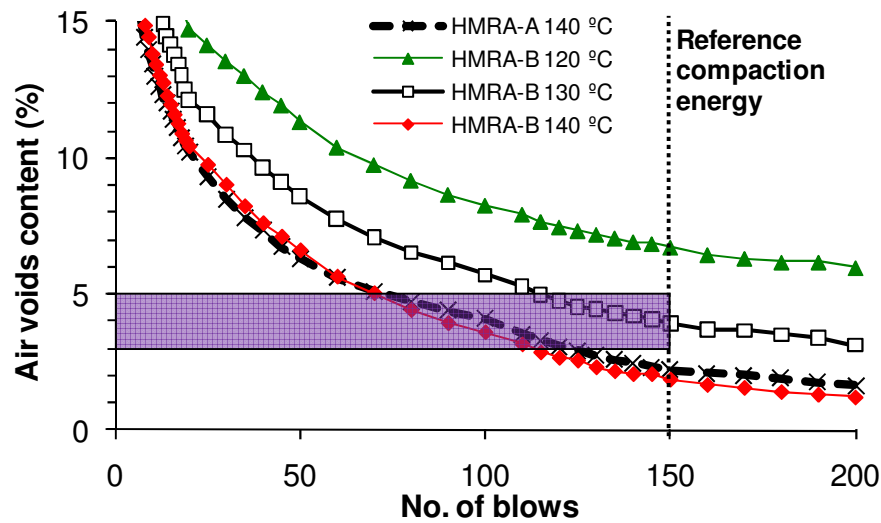
Use of surfactants in recycled and asphalt rubber WMA mixtures

- > Surfactants barely change the binder properties;
- > Temperature reduction was based on compactability tests (EN 12697-10);
- > The control mixtures were compacted at 140 °C (HMRA-A) and 170 °C (AR-SMA-A);
- > Three HMRA-B mixtures were compacted at 140, 130 and 120 °C;
- > One AR-SMA-B was compacted at 140 °C.

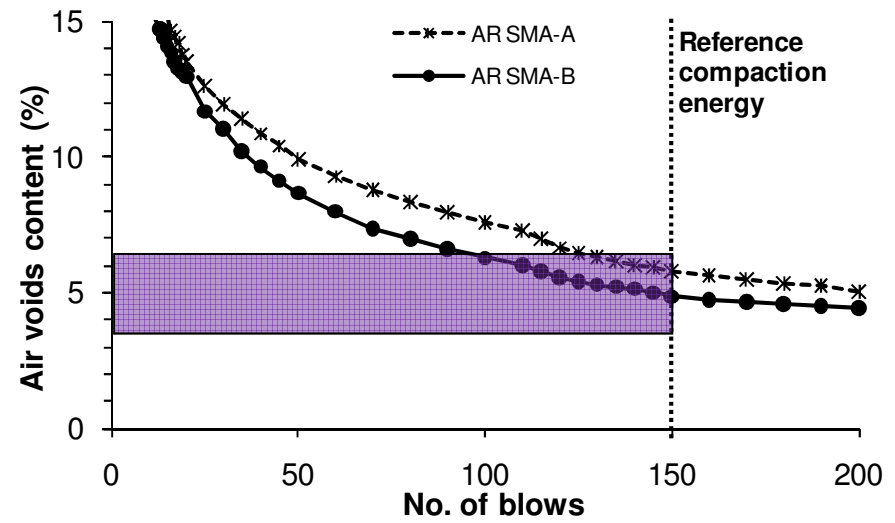


Use of surfactants in recycled and asphalt rubber WMA mixtures

> Compactability test results using impact compactor



HMRA



AR - SMA

The compaction temperatures could be reduced by 10 °C (40 °C in heating the virgin aggregates) for the HMRA and 30 °C for the AR mixtures

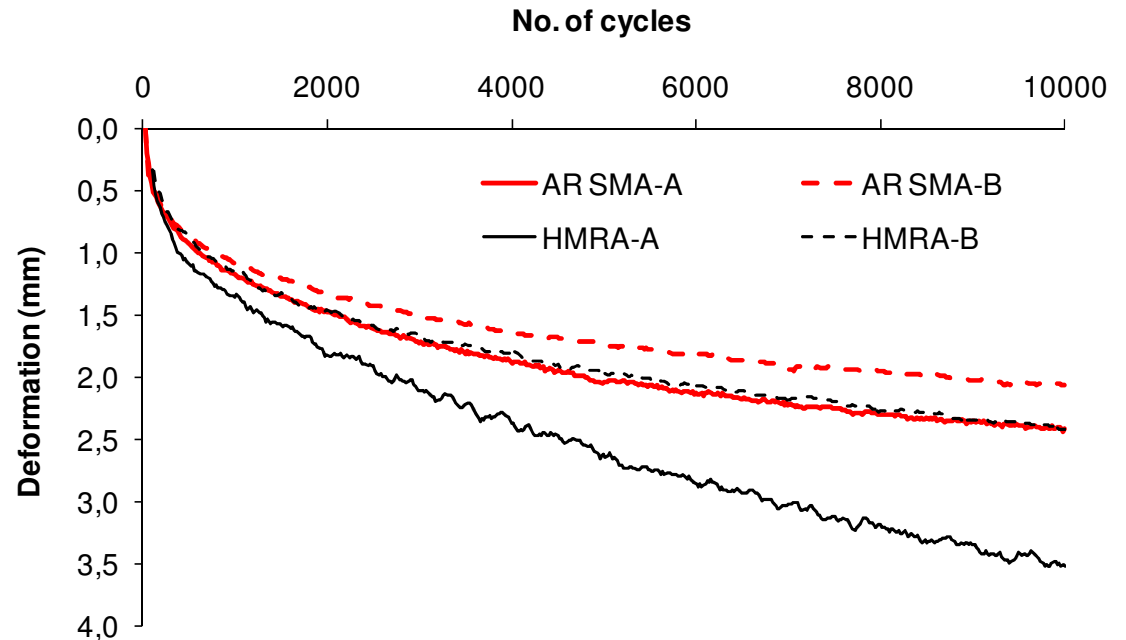


Use of surfactants in recycled and asphalt rubber WMA mixtures

> Resistance to permanent deformation

Wheel tracking test results

Mixture	WTS _{AIR} (mm/10 ³ cycles)	PRD _{AIR} (%)
HMRA-A	0.18	8.19
HMRA-B	0.09	5.68
AR SMA-A	0.08	5.54
AR SMA-B	0.07	4.78

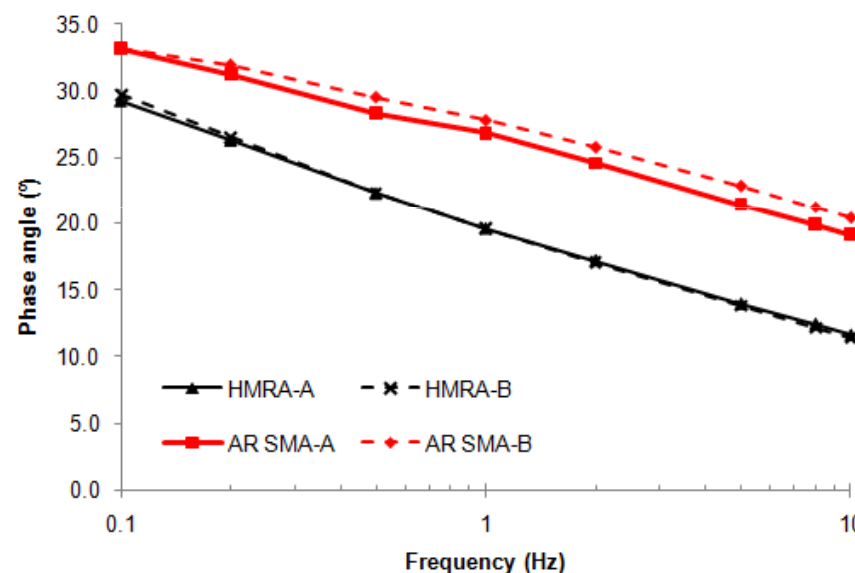
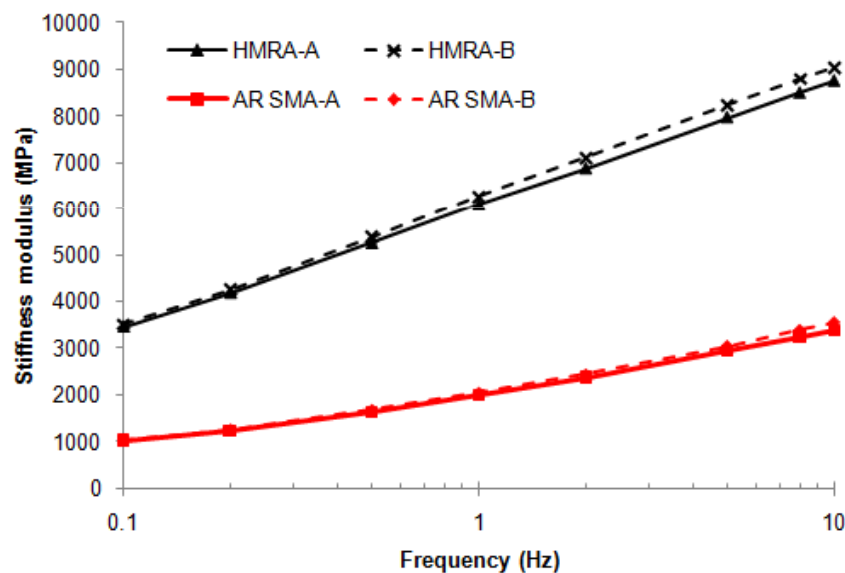


The introduction of the additive has increased the resistance to permanent deformation



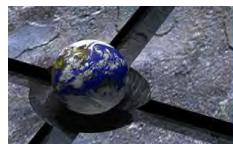
Use of surfactants in recycled and asphalt rubber WMA mixtures

> Stiffness modulus



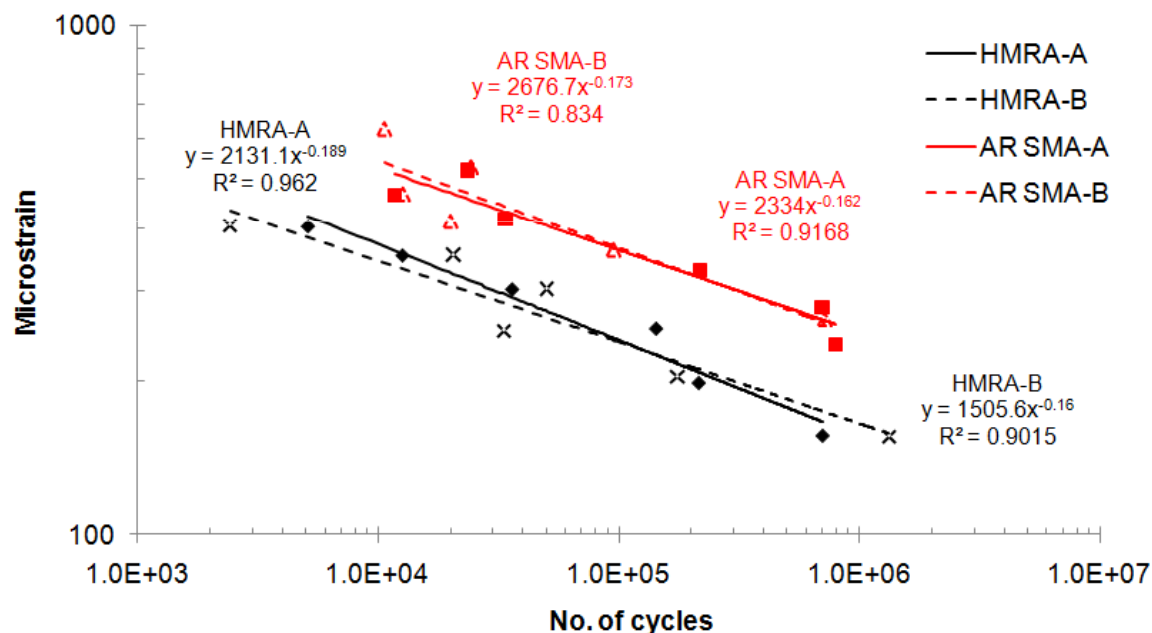
Stiffness test results, carried out at 20 °C, using 4-point bending apparatus

The additive barely affects the stiffness and the phase angle of the mixture



Use of surfactants in recycled and asphalt rubber WMA mixtures

> Fatigue cracking resistance



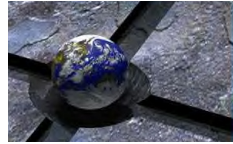
This confirms the possibility of using lower production temperatures

Fatigue test results, carried out at 20 °C, using 4-point bending apparatus

The additive does not affect the fatigue resistance of both types of mixture



CONCLUSIONS



Comparison between HMA and WMA mixtures

- > By using 4% of wax and 0.3% of surfactant the mixing temperatures were reduced 15 and 35 °c;
- > The lab performance of WMA mixtures was similar to that of HMA control mixture;
- > The WMAs produced in plant at target temperatures and laid down in the trial had adequate composition but shown performance problems (mainly rutting susceptibility due to fuel contamination);
- > The structural and functional properties of surface layer with HMA and WMA mixtures were similar.



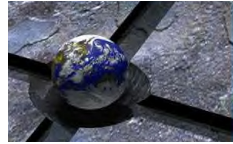
Unusual blends of wax + bitumen in WMAs

- > Softer base bitumens with synthetic paraffin wax additives are good to maximise WMA's temperature reductions (40 °C – HMBM; 30 °C – HFBM);
- > This additive significantly increases the resistance to permanent deformation of WMA mixtures;
- > The stiffness moduli of both WMAs was lower than those of corresponding HMAs (soft base bitumen);
- > The fatigue resistance of the HFBM WMA was significantly higher than HFBM HMA, while the behaviour of both HMBMs was similar.



Surfactants in Recycled and AR mixtures

- > By using 0.5% of additive, it was possible to reduce 40 or 30 °C, the production temperature of recycled (virgin aggregates) and AR mixtures, respectively;
- > The surfactant has increased the resistance to permanent deformation of both mixtures;
- > The use of surfactants and the reduction of temperature barely affected the:
 - Water sensitivity
 - Stiffness modulus
 - Fatigue resistance



Future research

- > Advantages of using Synthetic waxes + Surfactants
- > Study of in situ performance of non-traditional WMA mixtures (validation of lab properties)
- > Definition of production methods in the plant
- > Evaluation of other WMA and half-WMA additives and technologies
- > Assessment of other physical-chemical properties of WMA additives, bitumens and mixtures
 - Does the synthetic wax behave like a filler within the binder?
 - How can the efficiency of surfactants be evaluated?



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Thank you for your attention

