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The Italian Experience on Warm-Recycled Asphalt Mixes: from Research to Motorway Construction Specifications

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18|22 23|27 ECCELLENZA

Outline

1. Introduction
2. Trial Section 2016
3. Conventional mechanical testing
4. S-VECD performance analysis
5. Interlayer shear bonding
6. FWD monitoring
7. Chemical evaluation of recovered PmB
8. Trial Section 2022
9. Environmental assessment
10. Five-step classification of WMA additives
11. Construction Specifications & Conclusions

HiPER Tech
Highway Pavement Evolutive Research

Guidance and Coordination Unit: autostrade per l'italia

Academic Research Unit: UNIVERSITÀ POLITECNICA DELLE MARCHE

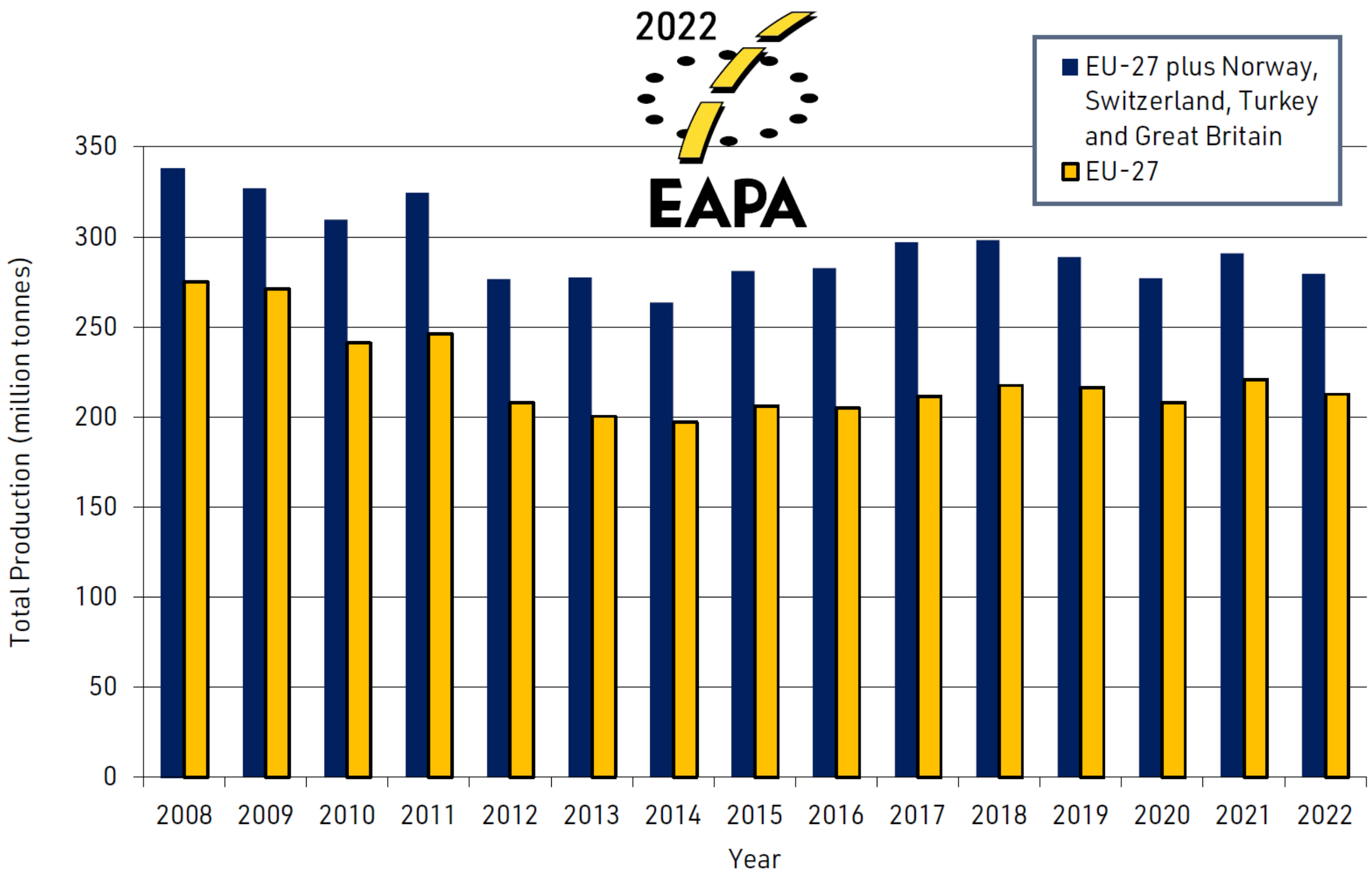
Operational Support Units: AMPLIA INFRASTRUCTURES

Reclaimed Asphalt Pavement Surplus

Total EU-27HMA and WMA production 2022

279,4 Mtonnes

- Mainly maintenance work
- HWA and WMA production = RAP
- Average RAP re-use = 30%
- **Huge amount of RAP surplus**



Source: Asphalt In Figures 2022 - EAPA

RAP as New Construction Material (no recycled material anymore)

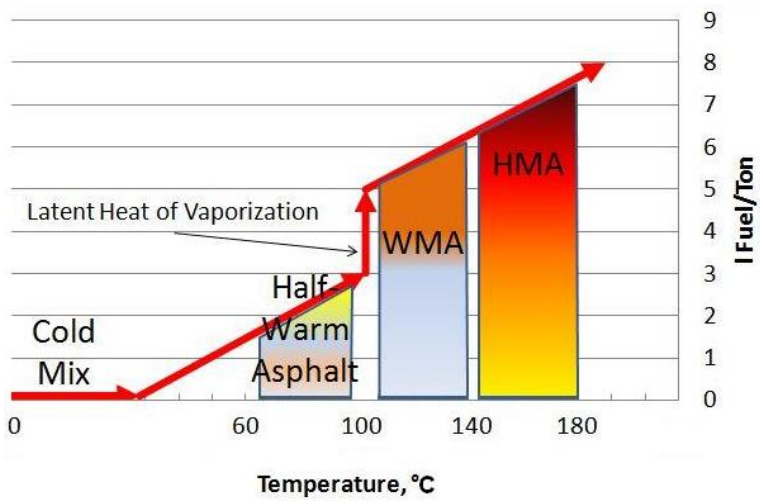
Reclaimed Asphalt Pavement

Hot and Warm Recycled Asphalt mixes:
Increase from current max 30%
to a viable **40-50% re-use**

Cold Recycled Mixtures:
Up to **90-100%** re-use

- Motorway maintenance work → mainly AC surface layers (no cold recycling)
- Cold Recycling → RAP = Black Rock (no reactivation)
- Bitumen → material from non-renewable resource: limited availability and negative outlook

Possible Solution for Sustainable Paving Mixtures: WMA Technology



- Reduction of production temperatures & energy savings
- Lower pollutant emissions & improved working conditions
- Longer hauling distances, extended time for paving, faster opening to traffic
- Lower bitumen aging & possibility to add higher %RAP

Limited data concerning:

- WMA long-term field performance
- Interaction between WMA additives and PmB

Autostrade per l'Italia Motorway Network (≈3000 km)

- ❑ **The largest Highway Operator in Europe**
- ❑ **High heavy-traffic volume → use of SBS PmB**
- ❑ **Continuous rehabilitation and maintenance activities**
- ❑ **Excess of huge amount of RAP (≈ 70%)**
- ❑ Narrow territory & Densely populated
- ❑ **Plants located near urban areas**

Challenge:
How can we reduce emissions and incorporate higher RAP amount without penalizing performance?

The Beginning

12 Asphalt Batch Mix Plant
(some of them near urban areas)

AMPLIA INFRASTRUCTURES

HMA with PmB			**WMA** with PmB		
STANDARD PRODUCTION T			**LOW PRODUCTION T**		
MIXING	=	**170 °C**	MIXING	=	**130 °C**
COMPACTION	=	**160 °C**	COMPACTION	=	**120 °C**

- 40 °C

Which Additive?

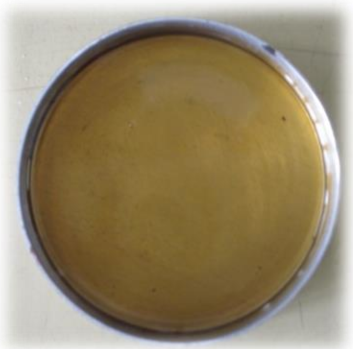
Organic additive O

To lower the viscosity at T > 90 °C. The additive is a special paraffin wax with long hydrocarbon chains.

Zeolite (water containing) Z

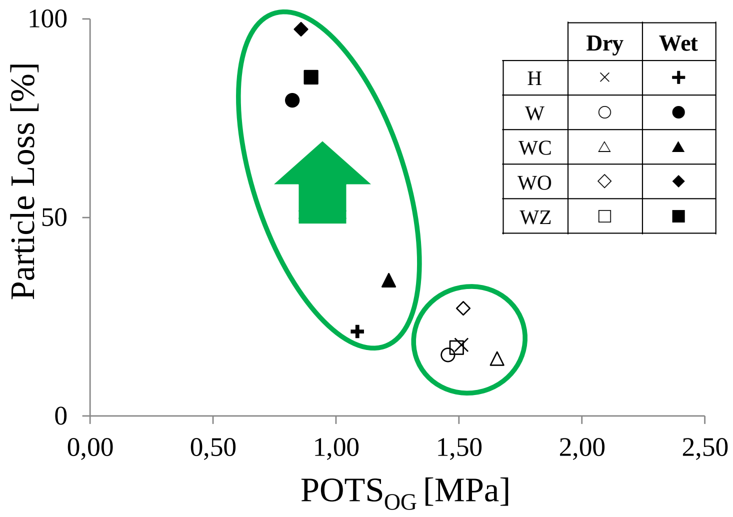
A foaming technique uses hydrophilic minerals with 20% of crystalline water, released at T > 100 °C.

Chemical additive C



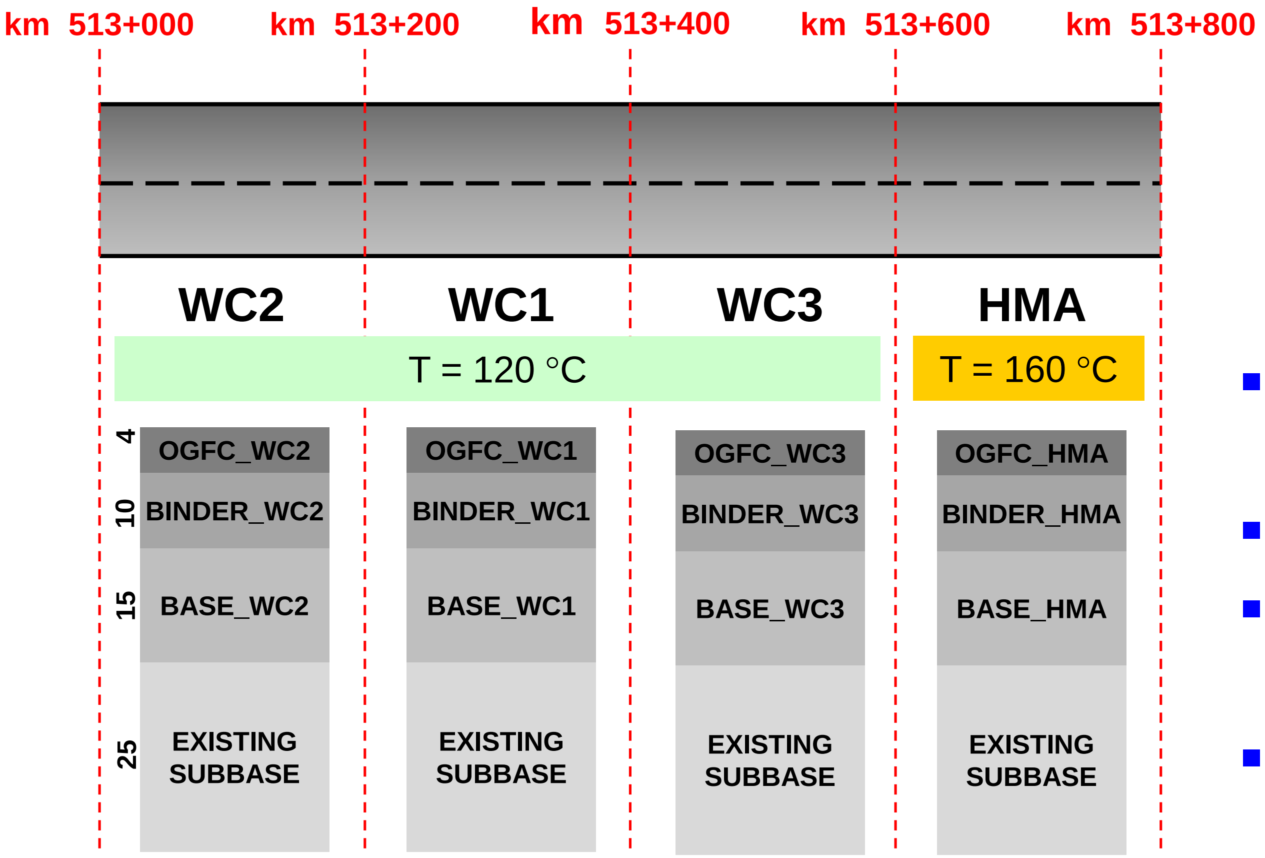
Do not change the bitumen viscosity. They act as surfactants at the binder interface by reducing frictional forces

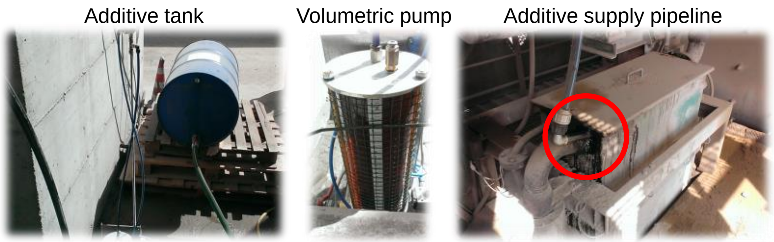
Wet conditions: only warm OG mixtures with Chemical Additive (WC) show good raveling performance



Selected WMA Technology for both DG and OG mixes

Motorway A1: 4 sections all containing PmB

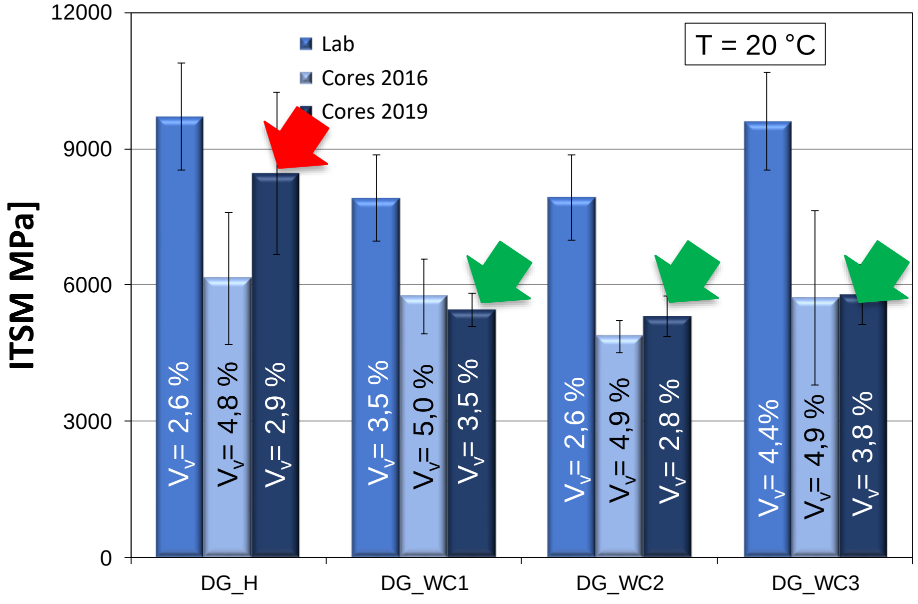


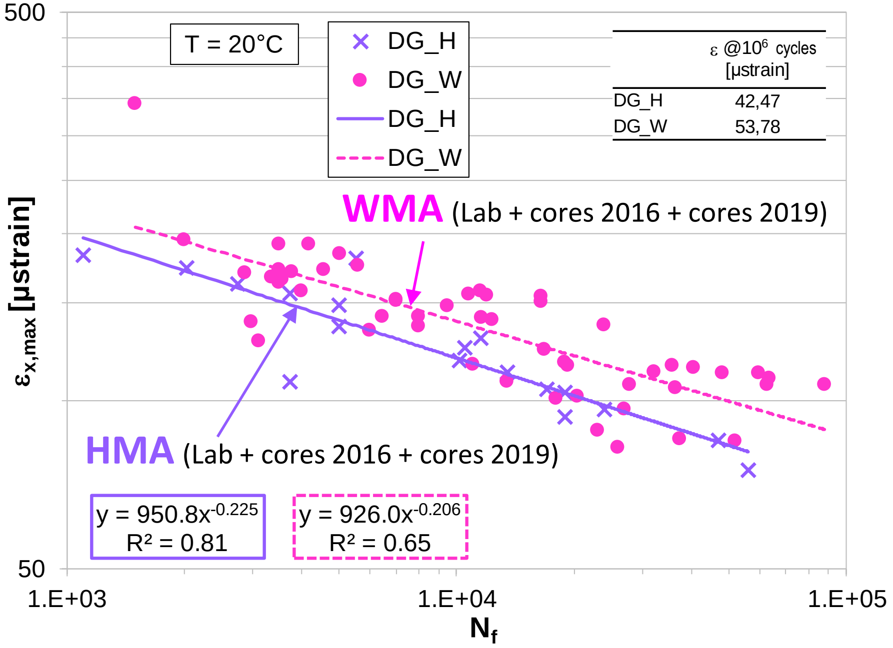


No significant modifications to the asphalt plant

- **Full-depth repair** after milling all existing asphalt layers
- 1 reference section with **hot recycled** mixes
- 3 sections: **warm recycled** mixtures with different chemical additives C1, C2, C3
- Same **climatic conditions** and **annual traffic** (**8,5 million ESALs 120 kN**)

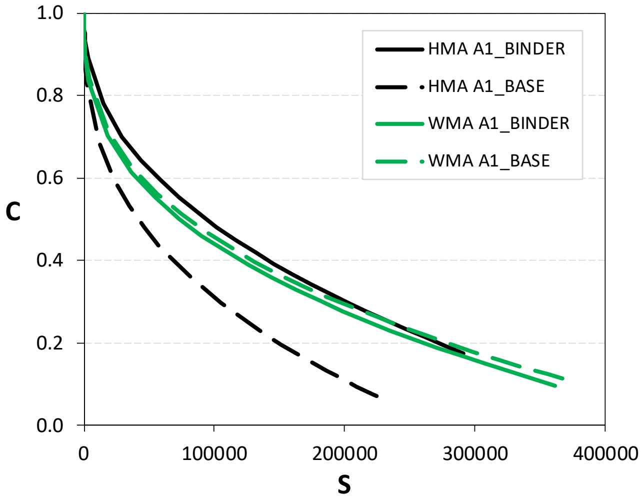
ITSM & ITF tests on laboratory specimens and in-situ cores (2016, 2019)

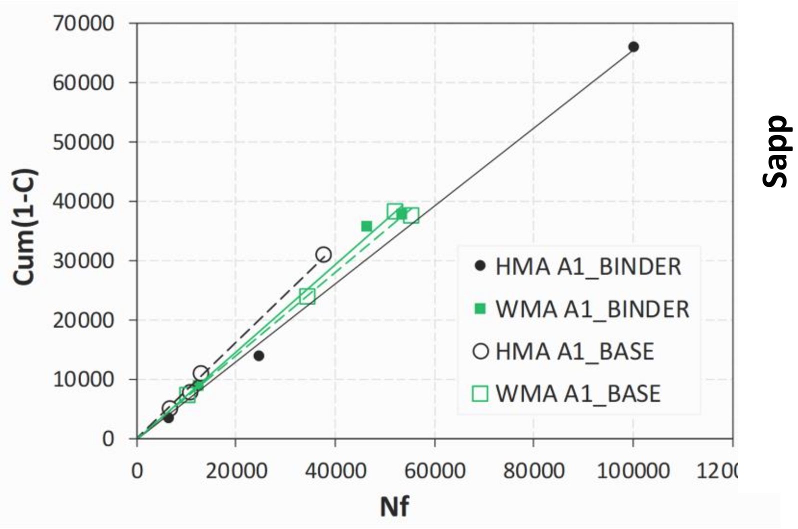


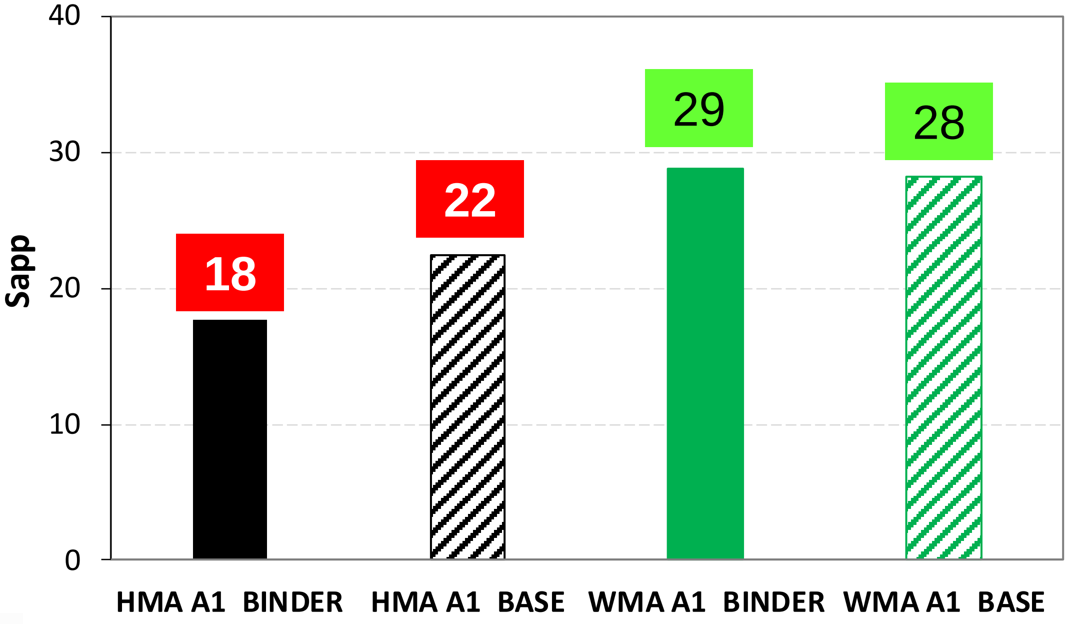


- Lab and cores 2016: similar ITSM values for **warm** and **hot** mixtures
- Cores 2019: higher variability for HMA and noticeable ITSM increase (severe aging effect?)
- Resistance to cyclic loading: **WMA** > **HMA**

HMA vs WMA_C1 in-situ cores (2022)







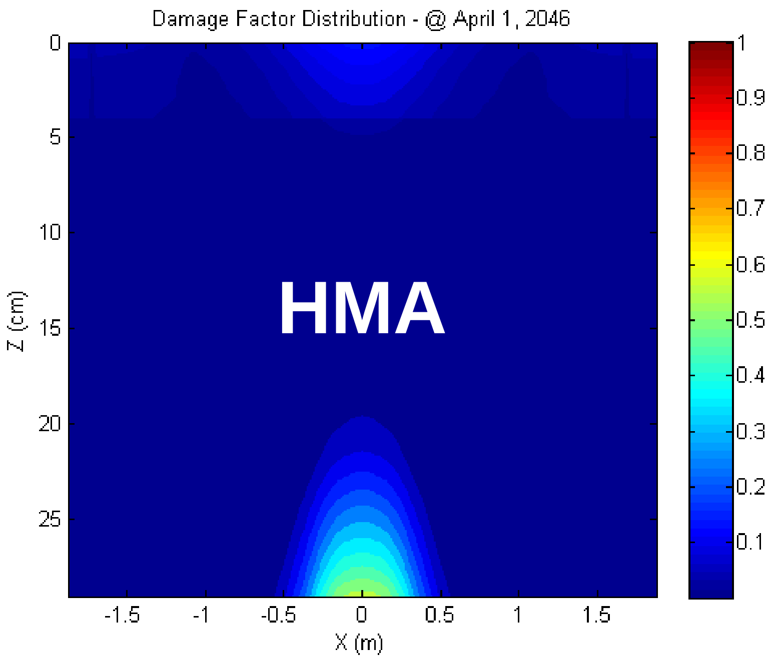
- *Sapp values* → based on the *C-S curves* and D^R values

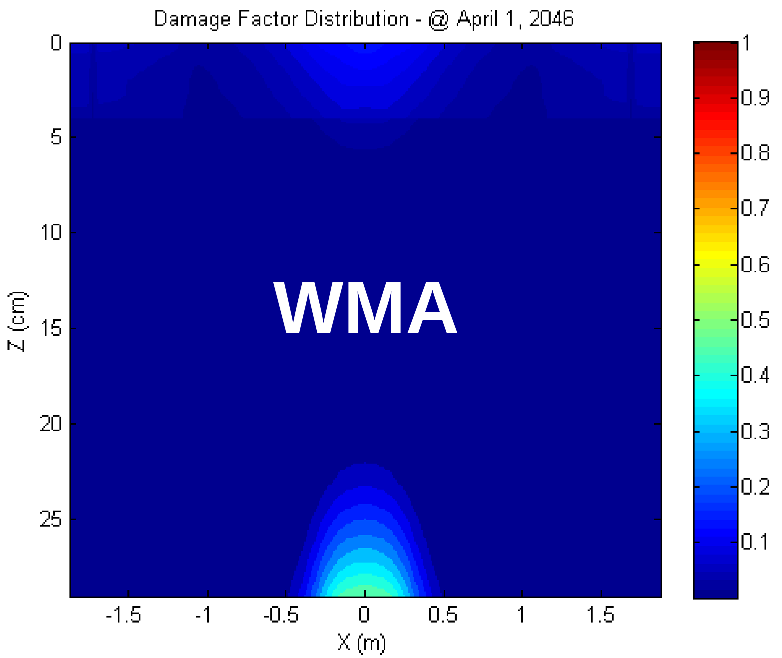
→ **A better fatigue performance can be expected from WMA,** similar for both binder and base layers, thanks to the **lower RAP oxidation**

HMA vs WMA_C1 in-situ cores (2022)

Damage contours

- 25 cm subbase E = 1200 MPa
- Prediction after 30 years
- Fatigue + climatic damage
- 8.5 mln – 120 kN ESALs
- v = 90 km/h





- Limited **top-down cracking** due to **thermal effects** in both sections
- **Bottom-up cracking** → about **9 cm** in **HMA** section vs. about **6 cm** in **WMA** section
- **Higher performance of WMA mixtures**

Background

Road Pavement = Multilayered structure

Overall performance depends on
Interlayer bonding behavior

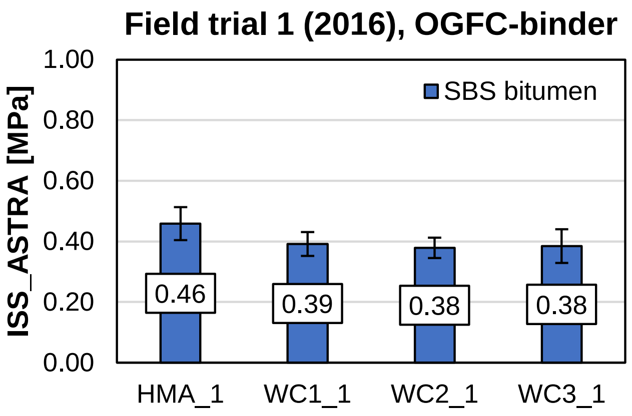
Full Adhesion — Perfectly Smooth

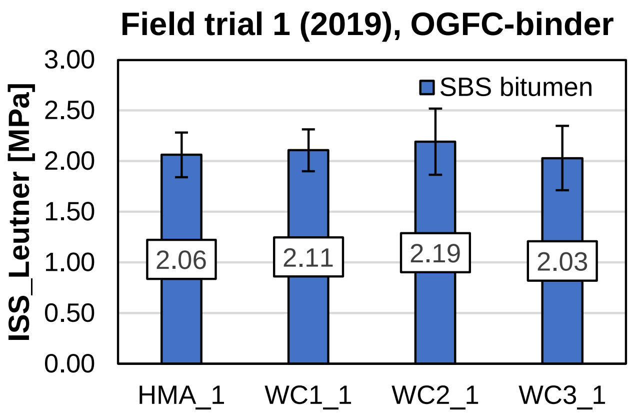
Interface

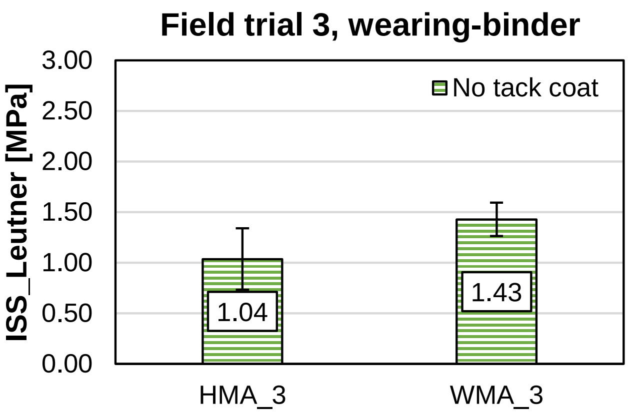
Real behavior: Intermediate & Evolutive

5. Interlayer Shear Bonding

Effects of WMA technology

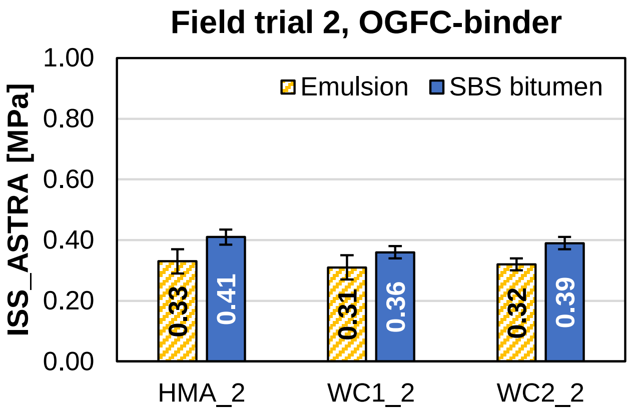


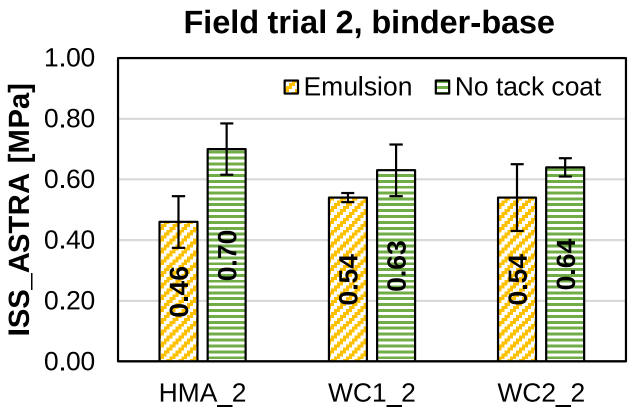




Variables investigated

- Effect of WMA technology
- Effect of WMA additive type
- Effect of age
- Effect of tack coat properties
- Effect of mixture type
- Influence of asphalt plant



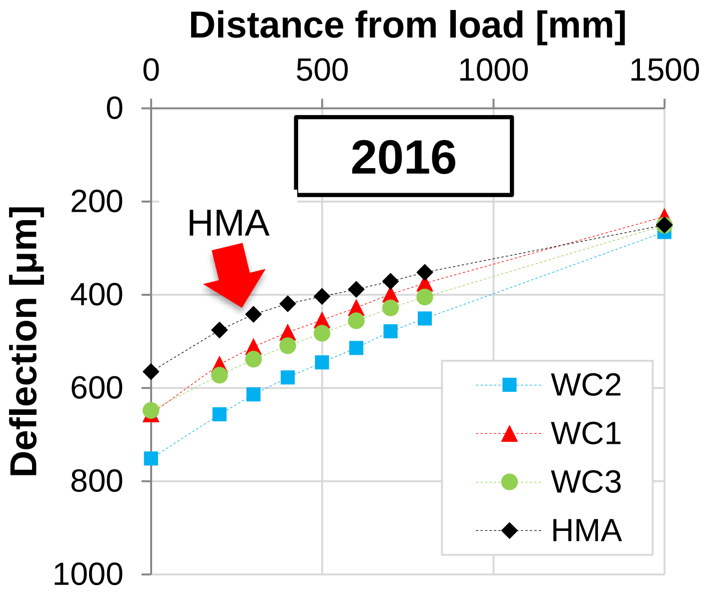


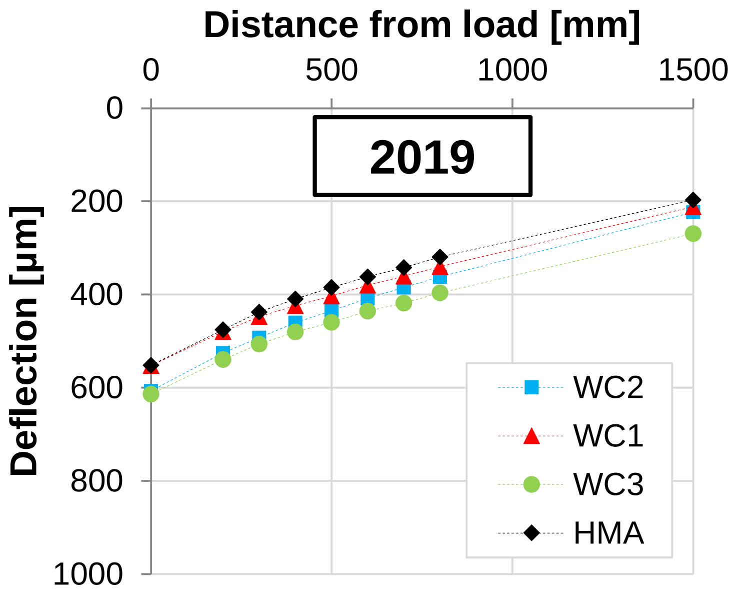
One-factor analysis of variance (ANOVA) with confidence level of 95%

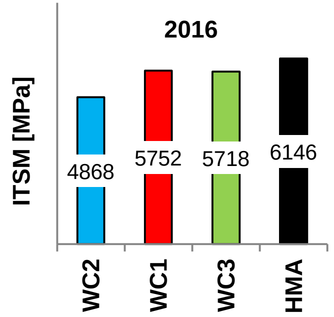
in most cases the **differences** between HMA and WMA **are not statistically significant**

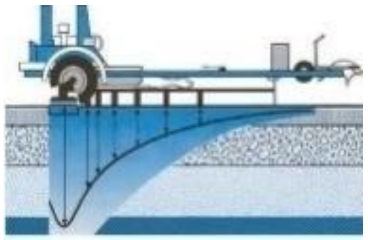
- **The reduced lay-down temperature** of warm mixtures **does not penalize the interlayer bonding**

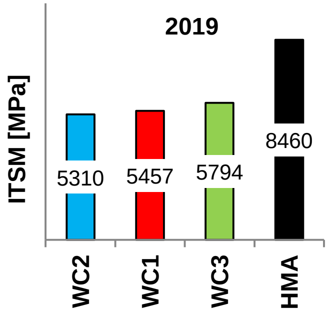
Representative FWD deflection basins – 2016 and 2019







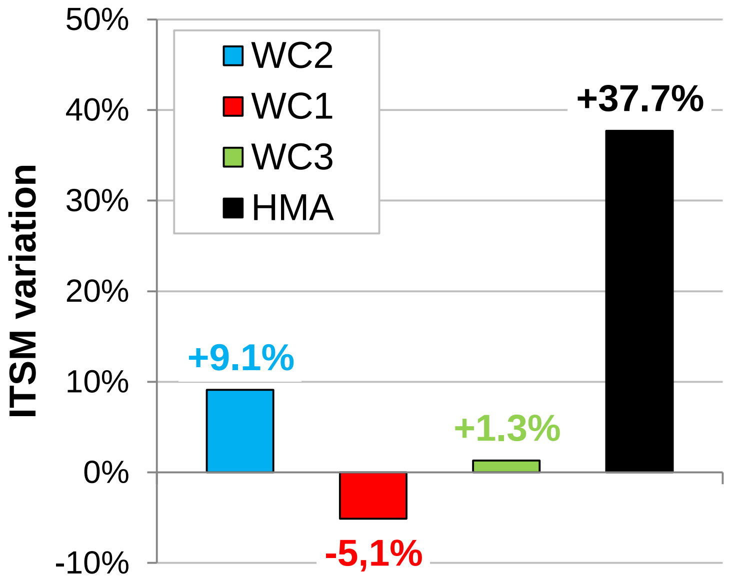




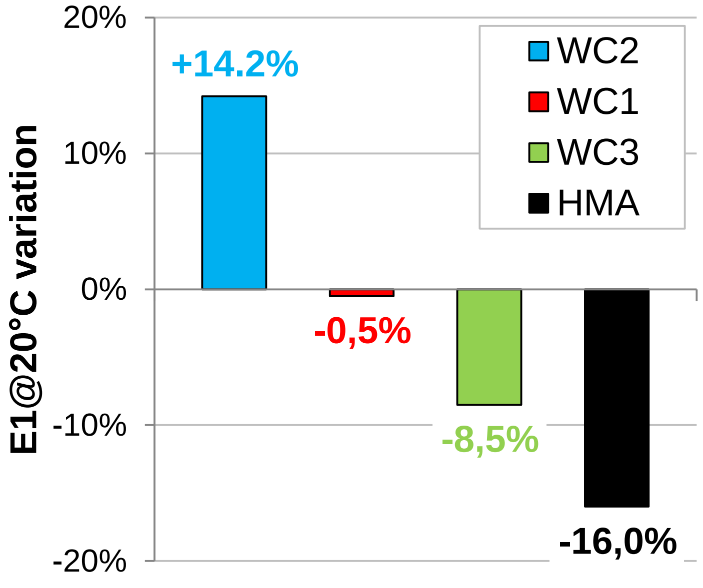
- ❑ 2016: good correspondence between deflections and ITSM
- ❑ 2016 and 2019: limited influence of the lower layers
- ❑ 2019 vs. 2016: changes attributable to the asphalt layers

Interpretation of the results

ITSM variation (2019 vs. 2016)



E1@20 °C variation (2019 vs. 2016)



- WC2: increase ITSM and E1@20 °C
- WC1 and WC3: almost no variation
- **HMA: increase ITSM and decrease in E1@20 °C**

The back-calculation expresses the layer performance, which corresponds to the mixture performance **only if the layer is intact**

HMA experienced the most severe aging → greater fracture and damage tendency

Warm recycled mixes may ensure higher performance and longer service life than hot recycled mixes

Recovered PmB: HMA & WMA_C1 in-situ cores (2022)

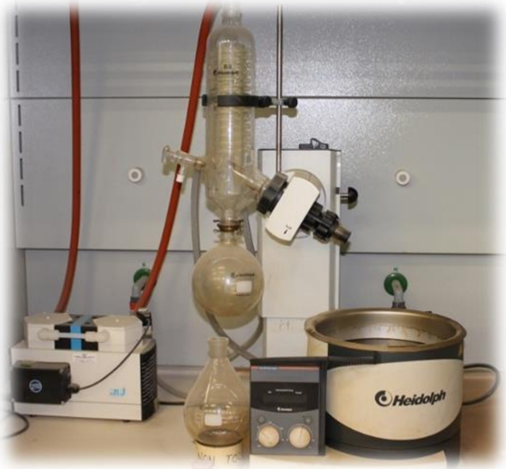
Porous wearing course **(open-graded OG)**

Binder course **(dense-graded DG)**

3 cores from each **HMA** and **WMA** section

Cutting phase

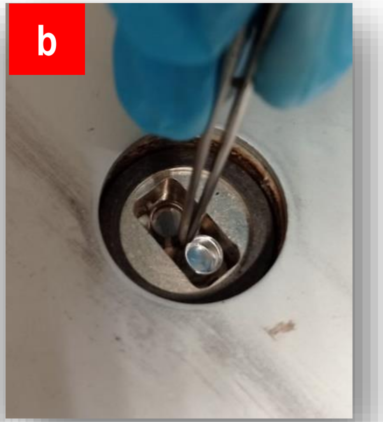
HMA	**OGH**
	DGH
WMA	**OGW**
	DGW

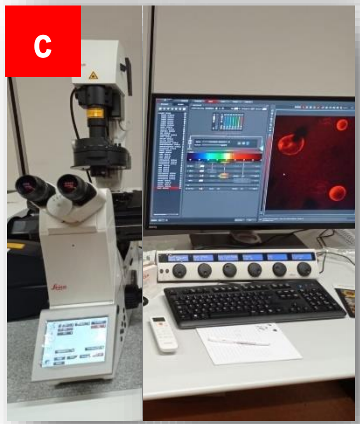


7. Chemical evaluation of recovered PmB

Methodology

Physicochemical characterization





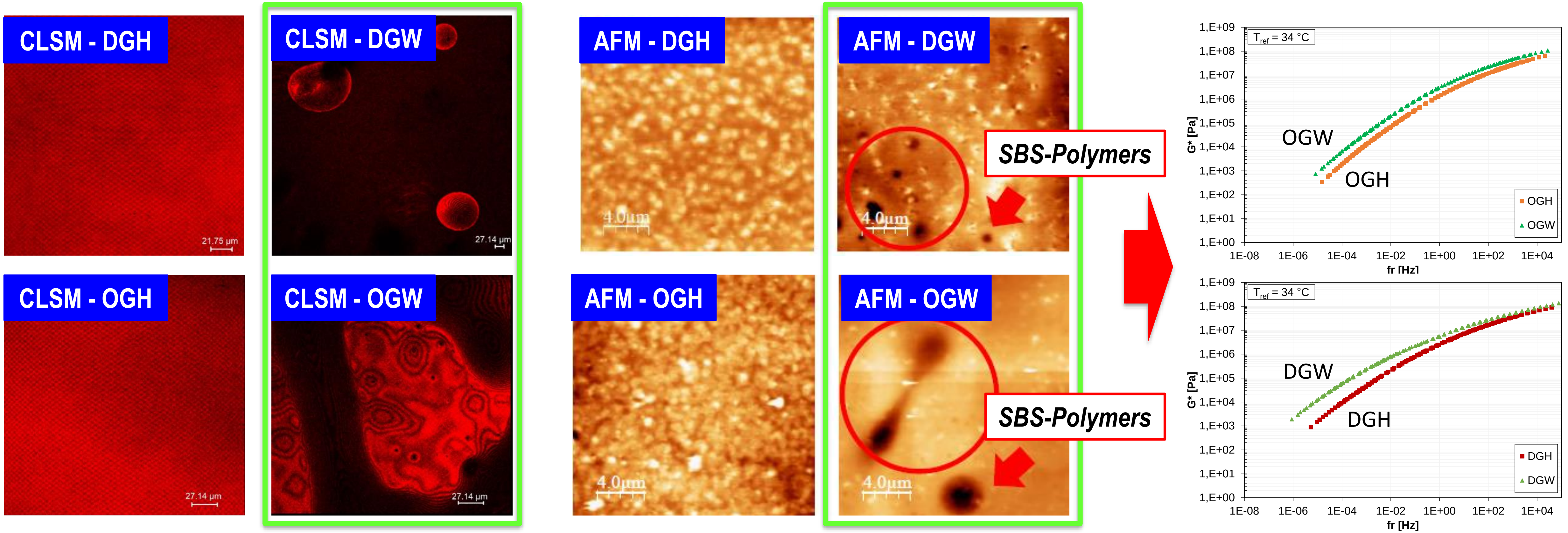
Rheological characterization

WMA recovered binders are less oxidized than the HMA ones

a. Nuclear Magnetic Resonance (NMR)
b. Differential Scanning Calorimetry (DSC)
c. Confocal Laser Scanning Microscopy (CLSM) & Atomic Force Microscopy (AFM)
d. Frequency Sweep tests (DSR)

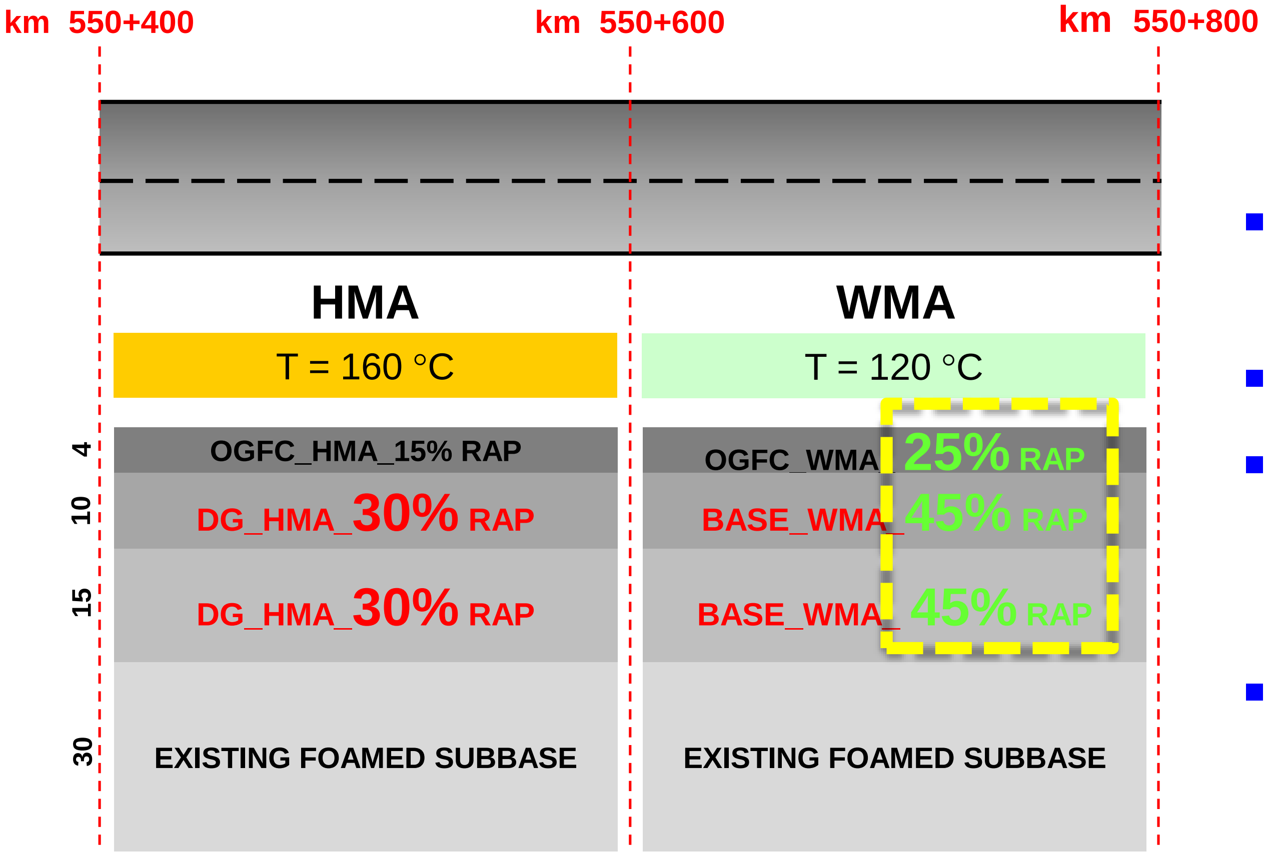
7. Chemical evaluation of recovered PmB

Confocal Laser Scanning Microscopy & Atomic Force Microscopy



- Same PmB: SBS-polymers recovered from Warm mixtures are **less degraded** (especially DGW).
- **Lower WMA T** → **Lower oxidation** but **prevent polymer degradation** → **Higher Stiffness**

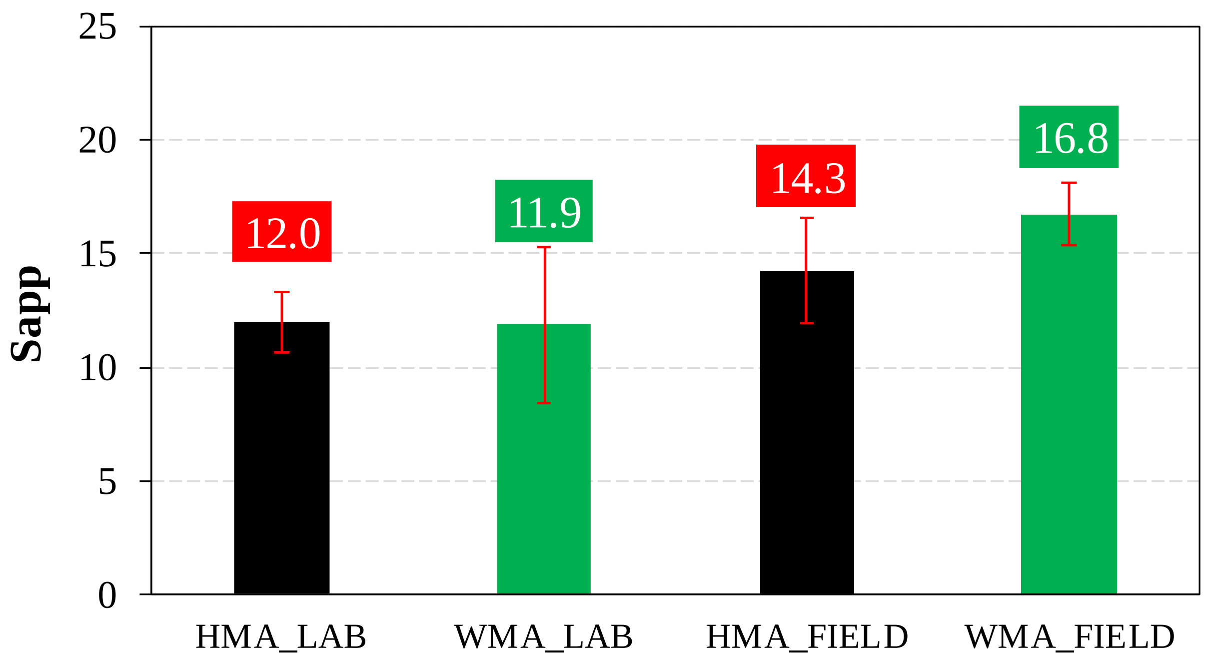
Motorway A1: 2 sections containing PMB



- **Full-depth reconstruction** after milling all existing asphalt layers
- Reference section with **hot recycled** mixtures
- Section with **DG warm recycled** mixtures **containing higher RAP** content, produced with chemical additive C1
- $T_{mix} – T_{comp}$: HMA 170-160 WMA 130-120

8. Trial Section 2022: DGAC with 45% RAP

S-VECD Analysys: HMA vs WMA_lab and in-situ cores (2022)



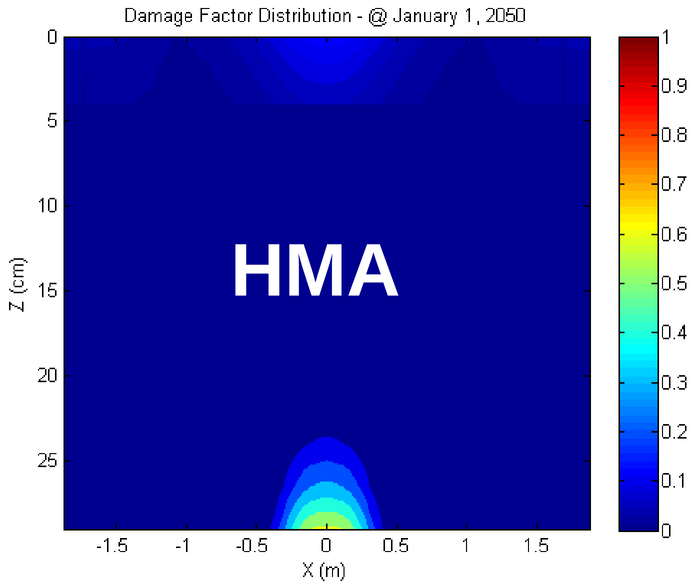
- *Sapp values* → reflect the observations on the *C-S curves* and D^R values

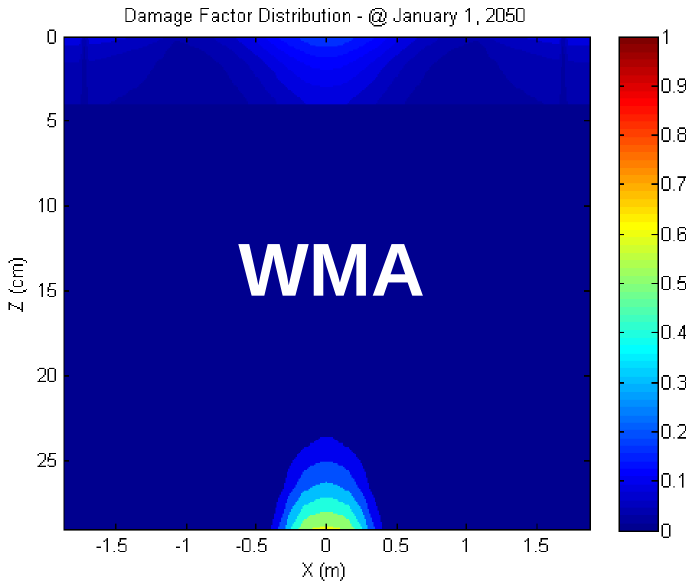
  → **A similar or better fatigue performance can be expected from WMA,** slightly higher in field conditions, thanks to the **lower RAP oxidation**

S-VECD Analysys: HMA vs WMA_lab and in-situ cores (2022)

Damage contours

- 32 cm subbase **E = 1200 MPa** (conventional unbound subbase)
- Prediction after 30 years
- Fatigue + climatic damage
- 8.5 mln – 120 kN ESALs
- v = 90 km/h



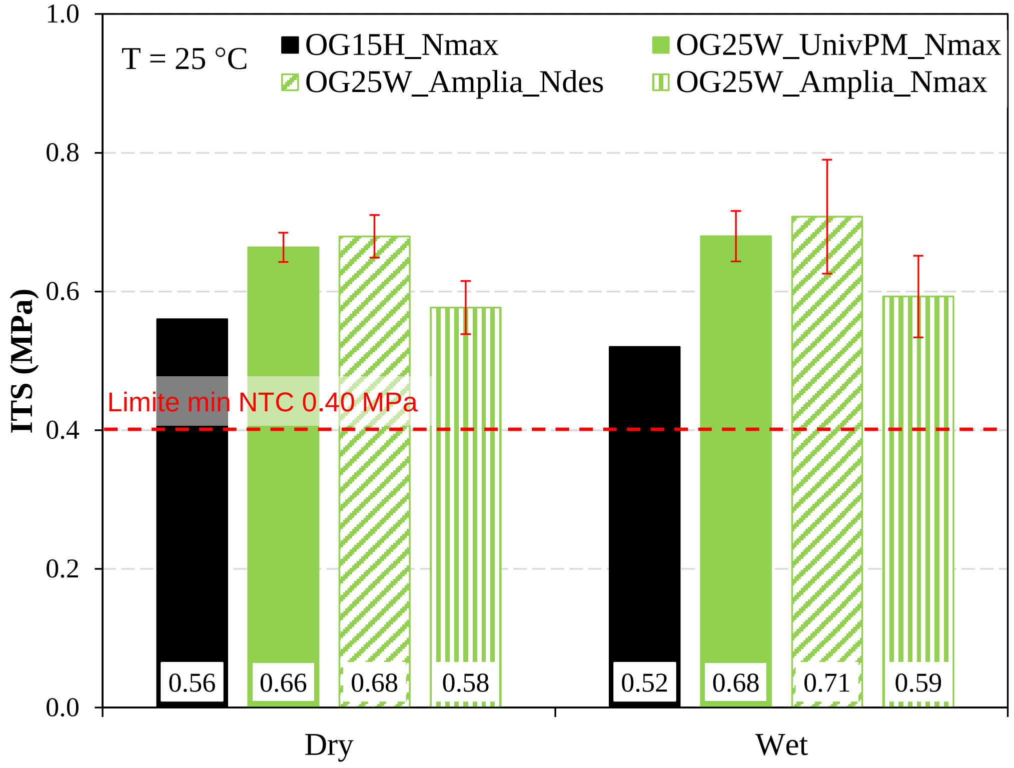


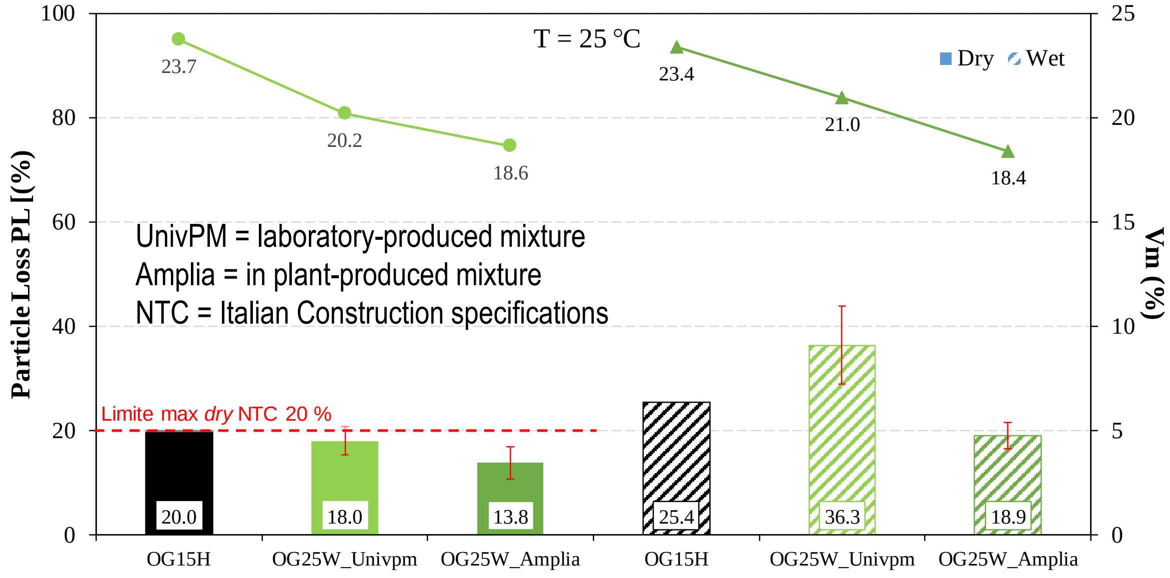
- Limited **top-down cracking** due to **thermal effects** in both sections
- **Bottom-up cracking** → about **7 cm** in **HMA** section vs. about **6 cm** in **WMA** section
- **Comparable performance of WMA and HMA mixtures**

8. Trial Section 2022: OGFC with 25% RAP

HMA vs WMA_laboratory-compacted specimens (2022)

Indirect Tensile & Cantabro Tests





- **ITS: OG_WMA > OG_HMA** (both wet and dry conditions)
- Good raveling resistance
- OG_WMA with 25% RAP satisfies the Construction Specs

Production at the asphalt plant

1. Drying/heating aggregate
2. Heating of the PmB (T = 170 ºC)
3. Mixing (WMA: **30 sec** @130 ºC; HMA: **26 sec** @170 ºC)

Asphalt Batch Mix Plant - *Amman Speedy Batch 180* with RAD90 drum

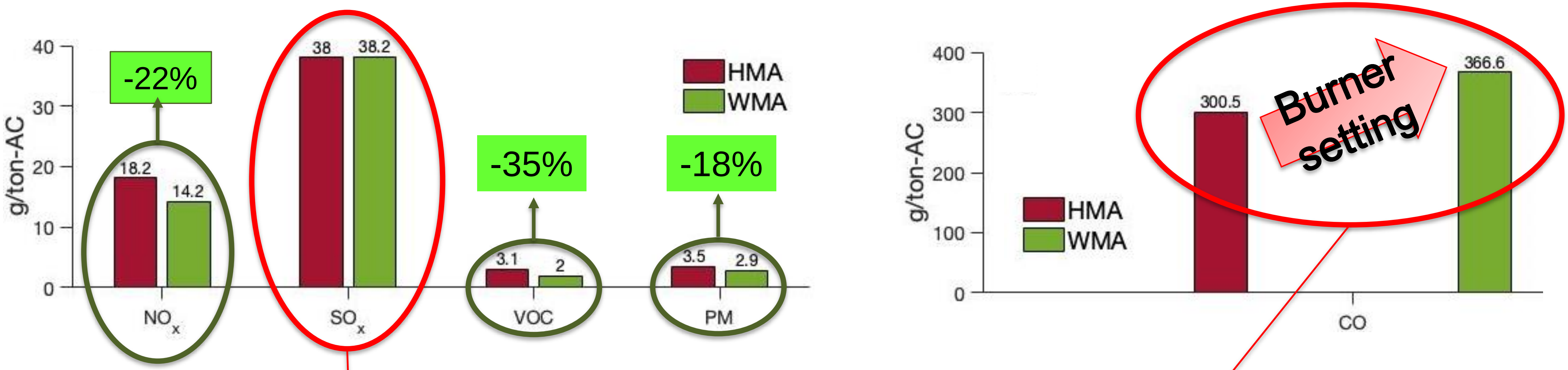
Calculated Parameters

Total CO_2 emissions per ton

Production phase	CO_2 emissions [kg/ton]								
	DGAC_base			DGAC_binder			OGAC_wearing		
	WMA	HMA	Δ	WMA	HMA	Δ	WMA	HMA	Δ
Heating aggregates	14.33	16.77	**-2.45**	14.62	17.22	**-2.61**	14.34	17.20	**-2.86**
Heating bitumen	0.79	0.79	—	0.92	0.92	—	1.19	1.19	—
Mixing	0.031	0.027	**0.004**	0.031	0.027	**0.004**	0.031	0.027	**0.004**
Total	15.15	17.59	**-2.44**	15.57	18.17	**-2.60**	15.56	18.42	**-2.86**
			-14%			-14%			-16%

Measured Parameters

Airborne pollutants emissions **at the stack of the drying drum** during the heating of aggregates



+1%

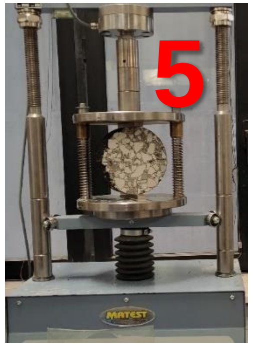
SOx and CO emissions today do **not** represent the most important environmental issue

+22%

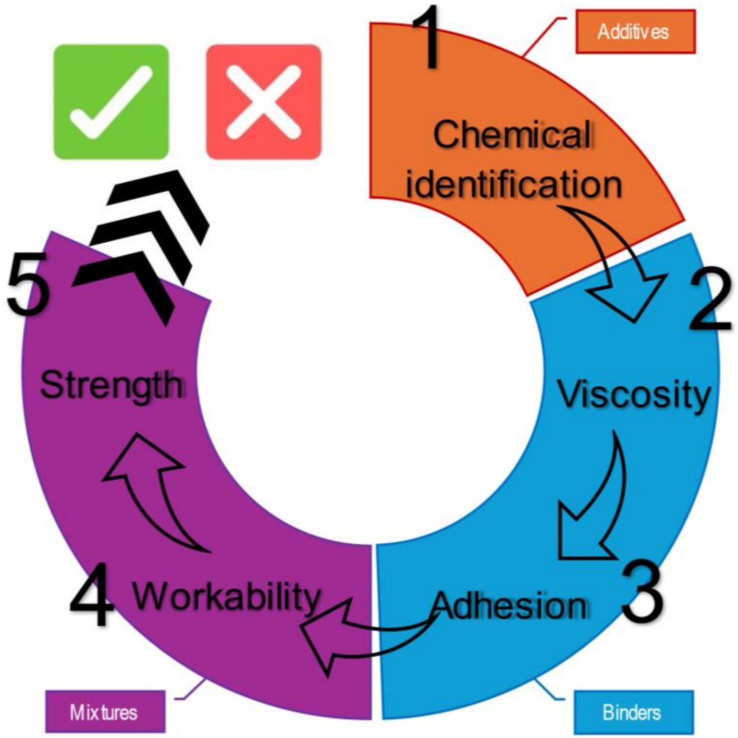
10. Five-step classification of WMA additives

Objective and testing protocols

Identifying a reliable experimental procedure to evaluate the effectiveness of WMA (chemical) additives

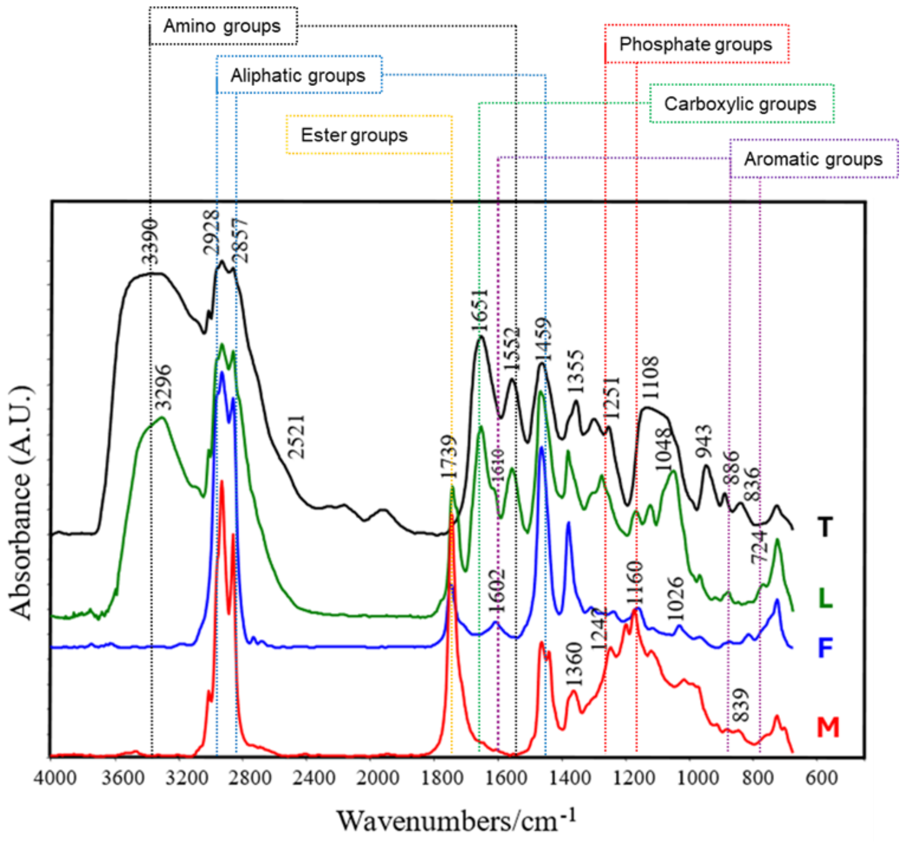


Step	Objective	Method	Parameter	Material	Repetitions
1	Chemical identification	FTIR	Functional groups	Bitumen, Additive	3
2	Viscosity	RV	η	Bitumen, Bitumen + Additive	2
3	Adhesion	BBS	POTS	Bitumen + Additive, aged Bitumen + Additive	5
4	Workability	SGC	CEI, AV	Hot-mix, Warm-mix + Additive	3
5	Strength	ITT	ITS	Hot-mix, Warm-mix + Additive	3

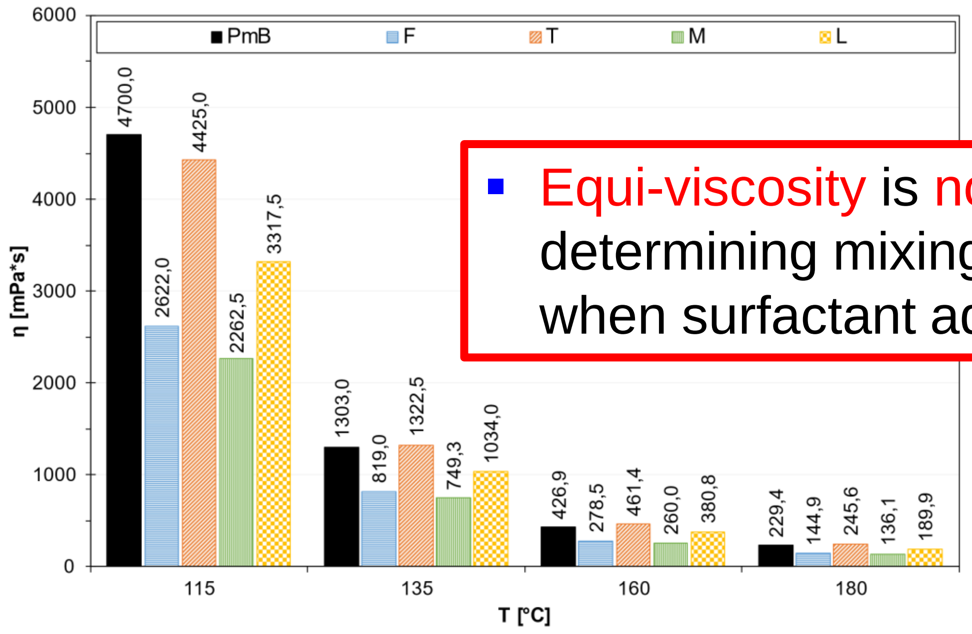


Step 1 & 2: Chemical identification (FT-IR) & Viscosity (RV)

- Different Functional Groups can be identified (amino, aliphatic, phosphate and esters groups) and linked to the adhesion and viscosity of the binder-additive blend.



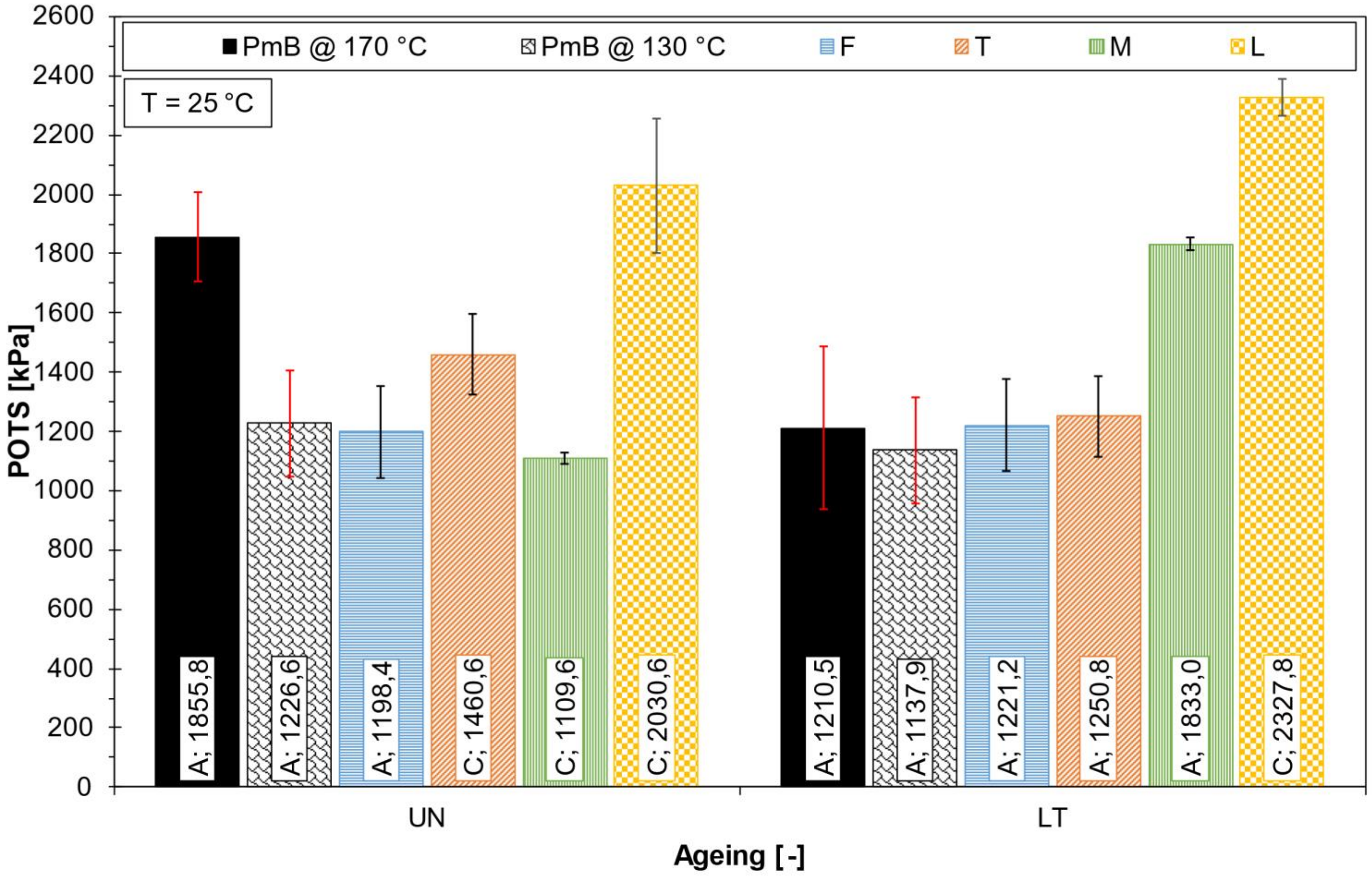
- Additives **F** and **M** act as a viscosity reducer whereas additive **T** acts as a surfactant



- Equi-viscosity is not suitable for determining mixing and compaction T when surfactant additives are used

10. Five-step classification of WMA additives

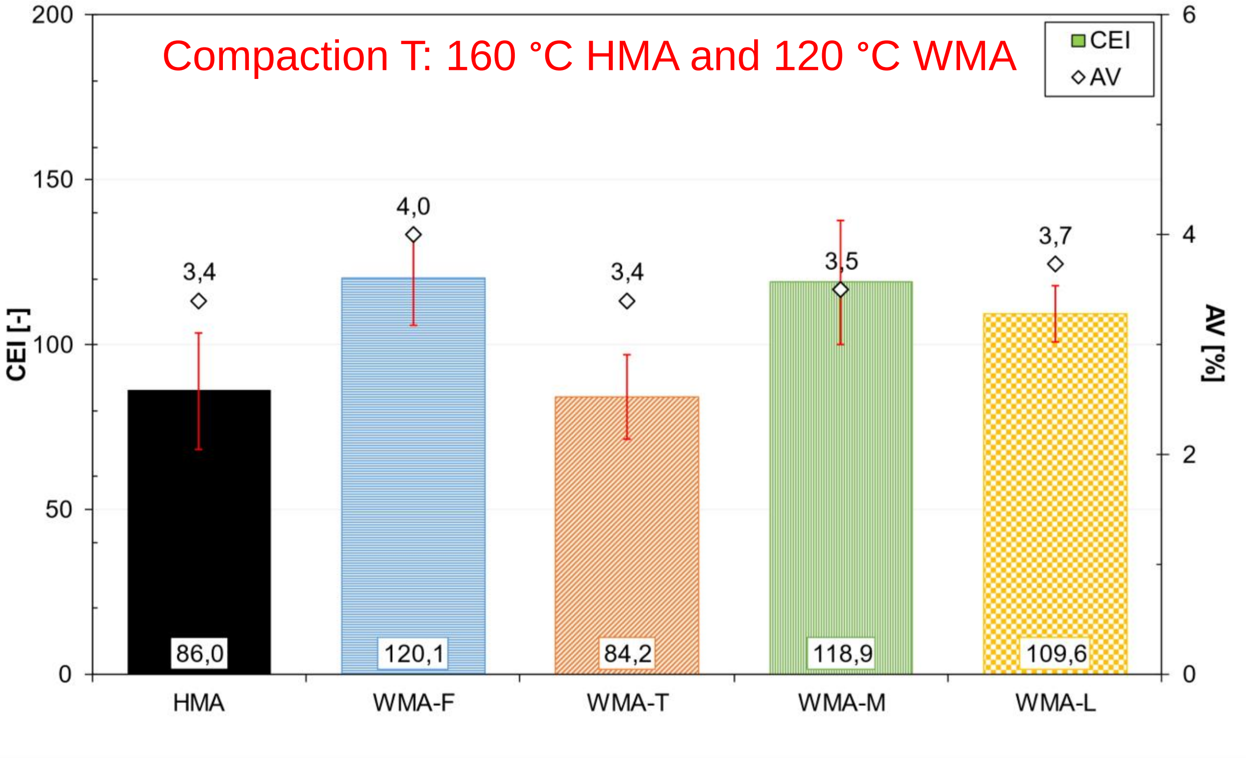
Step 3: Influence on the adhesion properties in wet condition (BBS)

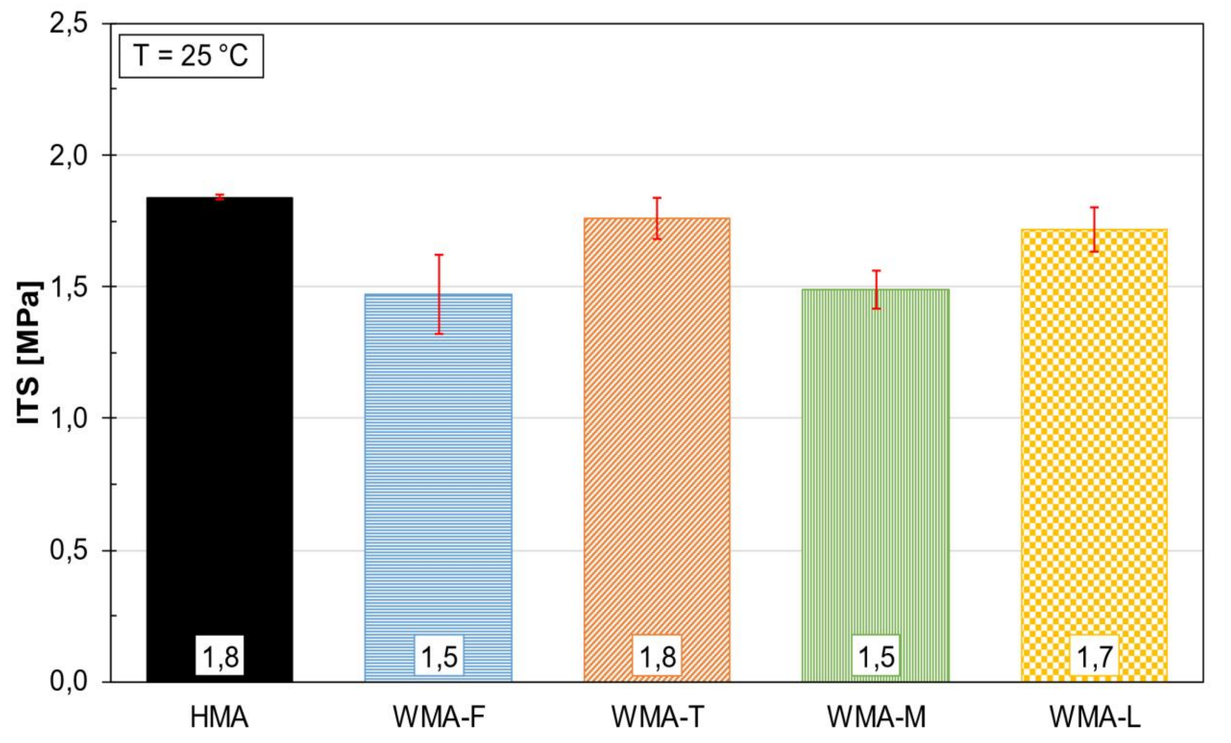


- Some additives reduce the adhesion in unaged bitumen (**F**, **M** and partially **T**) due to “warm” test temperature
- Some additives restore adhesion of long-term aged bitumen (**M** and **L**).

10. Five-step classification of WMA additives

Step 4 & 5: Mixture workability (CEI) and Strength (ITS)





- AV and CEI parameters of warm mixtures are strongly affected by the chemical additive used
- Further validation with advanced mechanical testing (in progress).

Synthesis of Requirements

- RAP can incorporate a considerable amount of water if exposed to rain up to 5% or higher (up to 8% during extensive precipitation).
- Stockpiling RAP in open sided sheds and on a paved and sloped surface is reccomended to allow the water to escape while protecting the RAP from rain;
- Before introducing RAP in the pugmill:
  RAP moisture content **≤ 4% for HMA** whereas **≤ 3% for WMA** (RAP ≤ 30%)
- Increased minimum bitumen content (lower RAP bitumen reactivation)
  AC base course: total bitumen content **≥ 4,0% for HMA** (RAP ≤ 30%)
  total bitumen content **≥ 4,3% for WMA** (RAP ≤ 30%)
- Longer mixing time is reccomended to promote RAP-Aggregate heat transfer: Typically, 15-20% extended mixing time is suggested
- Lower production and compaction temperatures (**-40 °C**):
  Production: **T ≤ 170 °C for HMA** whereas **T ≤ 130 °C for WMA**
  Compaction: **T ≤ 160 °C for HMA** whereas **T ≤ 120 °C for WMA**

Some numbers related to ASPI motorway network 2023

Total asphalt concrete (2023)

- DGAC 524800 ton → **Warm** DGAC 46800 ton (**9%**)
- OGAC 462000 ton → **Warm** OGAC 63150 ton (**14%**)
- **-300 ton CO2 equivalent**
- **≈ -17% fuel consuption**

(source: EPD AMPLIA Magliano Sabina – Asphalt Batch Mix Plant - *Amman Speedy Batch 180* with RAD90 drum)

Mixture	*ΔRAP (%)*	*Production (ton)*	*ΔRAP (ton)*
DGAC	+15%	2700 ton	+410 ton
OGAC	+15%	25850 ton	+3870 ton
	+25%	19300 ton	+4830 ton
			+9110 ton

Warm-Recycled Asphalt Mixtures as “Win-Win” Technology

Based on experimental results in terms of:

- Multi-approach analysis of mechanical performance & Interface bonding
- In-situ NDT monitoring of pavement bearing capacity evolution
- Chemical effects on PmBs
- Environmental assessment

Road Agencies: Higher Performance + Lower Pollution + Circularity

Construction Companies: Easy Production & Construction Implementation + Low additional costs (in Italy < 2 $Euro/ton_{AC\text{-}mix}$)

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