Environmental and mechanical evaluation of warm mix asphalts in laboratory and on site

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ABSTRACT

Warm asphalt mixes made with ready to use binders or with other types of technology like bitumen foam are commonly used in France and elsewhere.
In order to develop knowledge on the different technologies, an experimental trial has been organized in September 2013 in partnership between TOTAL Marketing Services, Eiffage TP and Ifsttar. The purpose of the test was to carry out environmental assessment of the warm mixes comparatively to traditional hot mixes. 4 sections have been realized (hot mix asphalt, warm mix asphalt with respectively ready to use binder, foam, and combination of foam and ready to use binder).
The asphalt plant had been equipped in order to record energy consumption and to monitor the chimney emissions.
On average the different warm mix technologies lead to savings on energy consumption and on greenhouse effect gases.
Extensive asphalt quality data like for example voids contents and macrotexture have also been recorded during the trial. Stiffness tests have also been carried out on cores. Performances of warm mixes are equivalent to the ones obtained with hot mix. A follow-up of the test is planned.

Keywords: Environment, Mechanical Properties, Warm Asphalt Mixture

1. INTRODUCTION & CONTEXT

Warm mix asphalts (WMA) are a relatively recent technique. It was developed in response to the needs of the road industry in decreasing the energy consumptions, in emissions reduction and in limitation of the workers exposure. Complementarily, public authorities encouraged this trend by calling on the road industry to tackle one of the key challenges of sustainable development: concentrate on saving natural resources for future generations while bringing industrial activities into a more stable long-term balance between environmental preservation and costs. As an example of this, in France, the main actors of the design, the implementation and the maintenance of the road infrastructures, the public road network and the urban public place signed in March 2009 an agreement of voluntary commitment with the Ministry of Ecology, Energy, Sustainable Development and the Town and Country Planning (MEEDDAT). It consists in particular in a commitment to reduce greenhouse gas emissions of the order of 33 % to the horizon 2020 [4].

The last ten years or so research and development efforts have been made by many stakeholders involved in the road industry to experiment and possibly develop numerous technologies for warm asphalt mixing. As a result literature is quite rich in studies in this field: environmental issues at the road pavement scale have been investigated through global methods, such as life cycle assessment and site data measurements. Another consequence of these efforts is that warm mix asphalts are commonly used across Europe, in particular in France, and in the rest of the world, e.g. in the United States of America. However, as road actors usually have their own preferred technique. While documented studies aiming at comparing different techniques in one same experimentation are scarce. And one should acknowledge the road owners, in their efforts to incorporate these new technologies, are still seeking more factual environmental information to clarify their decisions.

In this context, EIFFAGE TRAVAUX PUBLICS, a leading figure in the European construction, public works and concessions sector, the IFSTTAR, a major player in the European research on the city and the territories, transportation and civil engineering, and TOTAL MARKETING SERVICES, a leading international oil, gas and solar company and the European leader of bitumen production and marketing, forged in 2011 an original three-parties partnership. It combines in a same collaboration expertises in bitumen formulation, in asphalt formulation, manufacturing and laying and in energy consumption and airborne emissions assessments methodologies. It aims at comparing WMA manufactured through different techniques regarding their performances, their environmental impact and their durability within time. A first trial took place in 2011 in North-West part of France in order to set up a methodology and to generate a first set of data. In order to gather more data a second experiment was organised in 2013 and is the object of this publication. This study presents the results of several road experiments testing different WMA manufacturing techniques.

2. MATERIALS & PROCESSES

2.1 Materials

Aggregates

Aggregates used are limestone types coming from SCMS Rossetto quarry.

Reclaimed asphalt Pavement (RAP)

A unique source of 0/10 RAP was selected, to ensure the homogeneity. RAP material was sheltered to keep the water content constant for the different experimentations.

Bitumen

Two bitumen grades were used for this study, both provided by TOTAL MARKETING SERVICES and produced in the TOTAL refinery in Feyzin, France:

- a normal penetration grade (NPG) 35/50 bitumen, and
- a special 35/50 bitumen, which consists in a bituminous formulation especially designed to reduce significantly the mixing, laying and compaction temperatures of road asphalts (WMA) compared to those of a “standard” hot mix asphalts (HMA) manufactured with a “standard” (or NPG) bitumen.

As Table 1 below shows, the basic characteristics of the binders are similar, given the reproducibility of the test methods.

Table 1: Characteristics of the bitumen

Characteristics	Standard test method	NPG 35/50 bitumen	Special 35/50 bitumen
Penetration at 25°C (1/10 mm)	NF EN 1426	41	38
Softening point (°C)	NF EN 1427	52.6	52.9

Asphalt mix design

A single mix design was considered for the whole study. It was an asphalt concrete made with a continuous 0/10 mm grading curve (Figure 1), with 20% of RAP and 4.4% of fresh bitumen by weight of the aggregates. The total binder content was set at 5.4%.

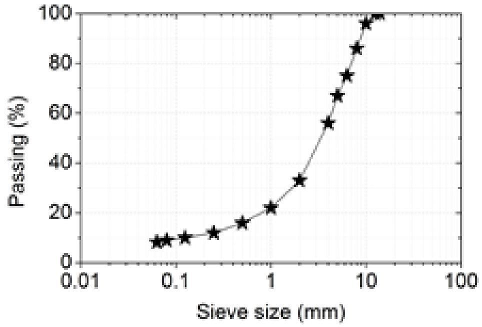


Figure 1: Aggregates size distribution of the "SCMS Rossetto" aggregates used in the considered asphalt concrete

2.2 Processes

2 different technologies were considered for this study for the manufacturing of WMA:

- Special 35/50 bitumen for WMA as described above.
- Foamed bitumen : WMA foaming technologies typically introduce limited amount of water into hot binder (>100°C) to create foam, which expands the binder and reduces the overall viscosity at relatively lower temperatures. The major foaming technologies can be divided into three categories as: (i) nozzle-based methods, (ii) indirect foaming via mixing hot aggregates with asphalt and wet fine aggregate and (iii) synthetic zeolite-based methods. In this study, the nozzle-based method is considered using a foam lab manufactured by ENH company (figure 2) for mixes design is the lab and by the AQUABlack® technology in the Ermont-Marini Plant.

Figure 2: ENH foam lab in EIFFAGE Travaux Publics laboratory in Corbas

2.3 Different configurations assessed

A total of 4 distinct configurations were tested for the study. 3 of them were WMA made from combination of the 2 technologies previously described in section 2.2 at a targeted temperature of 135°C. The other one is the referenced HMA produced at a temperature of 165°C:

- HMA made with NPG 35/50 bitumen
- WMA made with:
    - Special 35/50 bitumen
    - Foamed NPG 35/50 bitumen
    - Foamed special 35/50 bitumen

2.4 Lab tests / pre-study laboratory

The study focuses on the following mix properties:

- Workability using a maniabilimeter according to NF P98-258-1
- Compactability using gyratory compactor (EN 12697-31)
- Water sensitivity (EN 12697-12)
- Rutting resistance (EN 12697-22)
- Complex modulus (EN 12697-26)

The results of workability measurements obtained for the four mixes in EIFFAGE laboratory are presented in Table 2. Whether for HMA or for the three WMA, the measured workability was about 50N. It was constant with a temperature decrease of around 30°C, from 165°C to 140°C for HMA and from 140°C to 110°C for WMA.
As a comparison , the upper force limit fixed in EIFFAGE laboratory to consider a mix "workable" is 100N.

Table 2: Workability measurements using a workabilimeter

Test temperature	**165°C**	**140°C**	**110°C**
HMA	41 N	41 N	-
WMA with special binder	-	48 N	43 N
WMA with foamed binder	-	46 N	54 N
WMA with foamed special binder	-	47 N	50 N

For the other assessed mechanical properties listed above, the results are summarized in table 2.

Table 3: Mechanical results from the laboratory study

	HMA	**WMA with special binder**	**WMA with foamed binder**	**WMA with special foamed binder**	**Specifications EN 13108-1 (French national foreword)**
Maximum density (EN 12697-5)					
ρ_{mv} (Mg/m^3)	2.458	-	2.464	-	-
Gyratory compactor (EN 12697-31)					
V (%) at 10 gyrations	16.7	17.8	17.1	18.5	-
V (%) at 60 gyrations	8.6	9.6	9.0	10.2	5.0 to 10.0
V (%) at 200 gyrations	3.7	4.8	4.3	5.3	-
Slope	-4.341	-4.303	-4.235	-4.352	-
Water sensitivity (EN 12697-12)					
Void content (%)	7.7	7.7	8.9	8.4	-
C_d at 7 days in dry conditions (kPa)	11 900	11 000	10 700	10 100	-
C_w at 7 days in wet conditions (kPa)	11 000	9 200	9 600	9 100	-
i/C (%)	92	84	90	90	70
Rutting resistance (EN 12697-22)					
Void content (%)	6.2	7.9	6.7	6.8	5.0 to 8.0

	HMA	WMA with special binder	WMA with foamed binder	WMA with special foamed binder	Specifications EN 13108-1 (French national foreword)
Slab thickness (cm)	10.1	10.2	10.3	10.3	
Test temperature (°C)	59.4	59.6	58.9	59.3	60°C ± 2°C
Rut depth (%) at					
1 000 cycles	2.1	2.4	2.4	2.6	-
3 000 cycles	2.5	2.9	2.9	3.0	-
10 000 cycles	3.1	3.6	3.4	3.6	-
30 000 cycles	3.4	4.2	3.9	4.1	≤ 5.0
Complex modulus (EN 12697-26)					
Void content (%)	3.6	6.3	4.7	6.3	5.0 to 8.0
E^* @ 15°C / 10Hz (MPa)	12 700	11 000	12 200	10 800	≥ 7 000

Considering the reproducibility of the different tests performed, and except few discrepancies in the void content of the complex modulus specimens, the three WMA can be considered equivalent to the HMA. In any case, they satisfy the specifications for the French “BBSG class 3”.

3 ON-SITE MEASUREMENTS

3.1 Asphalt mixing plant

The plant used for this study is a drum plant called SEVA (Figure 3). It was manufactured by Ermont-Marini (Fayat Group) in 2012. It allows the use of a RAP content up to 50% thanks to the two RAP introduction points in the ring and in the pug mill. The plant was also fitted with a foam kit.
The plant can reach a mixes production rate of 190 tons per hour.

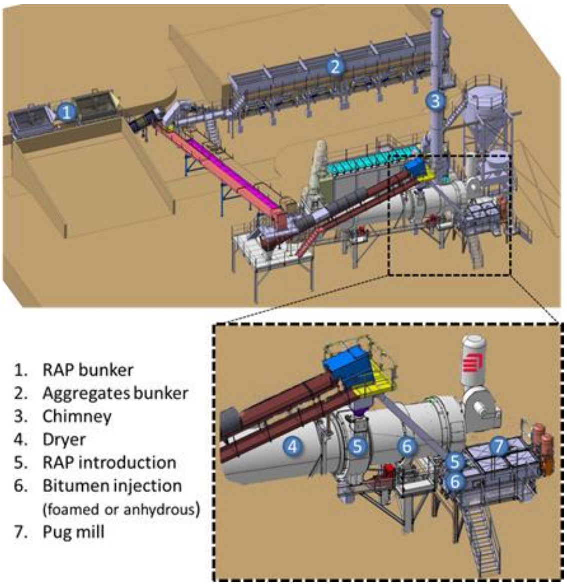


Figure 3: Schematic of the SEVA plant

3.2 Mechanical assessment at the application site

- **Road sites**

The 4 different asphalt mix types were laid between the 11th and the 13th of September 2013. It was not possible to lay the 4 types on the same road section as no big enough roadwork could be organized at the time. Consequently 3 of the asphalt mix types were applied on one section in Lucinges whereas the last one was laid in a different location at Entremont. These 2 road sites were located in the French Alps area.
The different sections configurations are detailed in the table 4.

Table 4: Characteristics of the road sections

	Section 1	**Section 2**	**Section 3**	**Section 4**
Location	RD183 Lucinges	RD183 Lucinges	RD183 Lucinges	RD12 Entremont
Distance from asphalt plant	10 km	10 km	10 km	30 km
Asphalt mix type	AC 10 WMA Foam with NPG 35/50	AC 10 WMA Foam with special bitumen	AC10 HMA (Ref) NPG 35/50	AC10 WMA Special bitumen
RA content	20%	20%	20%	20%
Day of laying	11/09 AM	11/09 PM	12/09 PM	13/09 AM
Weather conditions	Cloudy – 20°C	Cloudy – 20°C-Rainy at the end of the laying	Cloudy 20°C	Sunny – Windy - 8°C

- **Laying conditions**

For all sections, 6 cm of 0/10 mm asphaltic concrete were laid using similar equipment : one Finisher type 7820 running at 4m/min with vibration 2500 rev/min followed by two Double drum vibratory rollers respectively 10t and 12t.

Figure 4: WMA application in Lucinges in september 2013

- **On site measurements**

Some density measurements have been carried out on site for the three WMA sections using nuclear gauges measurement. The results are summarized in the table 5. The average void content is a bit higher than the target (4 to 8%) for the section 4 probably due to more adverse weather conditions and some problems with the compaction rollers during the laying. Some texture measurements have also been realized and are very similar for the three sections.

Table 5: On site measurements

	Section 1	Section 2	Section 4
Average void content (NF P 98 241-1)	8.2%	7.0%	9.2%
Average Texture depth (EN 13036-1)	0.65 mm	0.65 mm	0.66 mm

As no measurements were carried out on the HMA (section 3), 4 cores were taken out of each of the 4 sections three months after the trial in order to check the bonding of the wearing course and the thickness of laying as well as to measure bulk density and stiffness.

- **Measurements on extracted cores**

The average results are summarized in the table 6. The average void content is generally lower than the one measured with the nuclear gauge and within the void content target of 4 to 8% except the section 4 where the void content is higher than the on-site measurement and clearly out of the target.
The stiffness of all the cores complied with French specifications for BBSG type of asphaltic concrete. The HMA shows a higher stiffness but the 3 WMA sections, including the less compacted one, are showing very good level of stiffness for this type of mix.
Moreover the binder was recovered from some of the cores and analyzed comparatively to the original binder in order to estimate the possible effect of mixing temperature on short term binder ageing. The results show however very little differences between the different process.

Table 6: Measurements on extracted cores

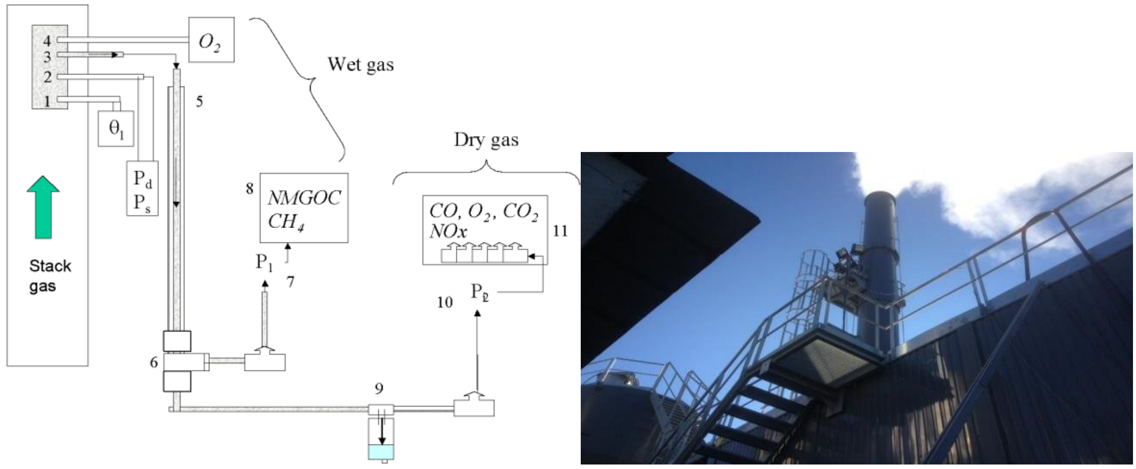
	Section 1	Section 2	Section 3	Section 4
Average cores thickness	5.2 cm	6.1 cm	5.6 cm	5.8 cm
Average void content EN 12697-7	6.8%	6.3%	6.0%	12.6%
Average Stiffness 15°C 10Hz EN 12697-26 / Appendix F	8800 MPa	9900 MPa	11000 MPa	8800 MPa
Original binder PEN (EN1426) SPT (EN1427)	41 1/10 mm 53°C	47 1/10 mm 52°C	41 1/10 mm 53°C	47 1/10 mm 52°C
Recovered binder PEN (EN1426) SPT (EN1427)	24 1/10 mm 60°C	20 1/10 mm 62.4°C	22 1/10 mm 61.4°C	22 1/10 mm 62.2°C

3.3 Environmental measurement

- **Methodology**

The hot and warm asphalt mixes were alternatively produced. All manufacturing processes were required to last at least an hour, in order to collect environmental data over a sufficiently long period.
At the plant, gas and electricity consumption were measured along with airborne emissions. At the main stack, volume fractions of O_2, CO_2, NO_x, CO, Non-Methanic Gaseous Organic Compounds (NMGOC) and CH_4 were all measured, as well as a number of physical parameters (temperature, static and dynamic pressures), in order to convert volume fractions into mass flows. However, in the present paper the results are focused on energy and greenhouse gas (GHG) of asphalt production.

The sampling and measurement principles at the main stack are presented in Figure 5. To avoid any compound condensation, the sampling device was heated to 180°C, from the sampling probe to the chemical analysis apparatus located at the bottom of the stack. At the roadwork site, the operating times for each machine (compactor and finisher) were measured in order to estimate machine energy consumption and emissions.



1: thermocouple - 2: standard Pitot tube (static Ps and dynamic Pd pressures) - 3: hot sampling probe - 4: O_2 analyzer for wet gases - 5: Heated sampling line - 6: heated T - 7: FID pump - 8: FID analyzer (Mercury 901, NIRA) - 9: water condenser (Peltier effect) - 10: multigas analyzer pump - 11: multigas analyzer (PG 250, Horiba)

Figure 5: Principles of gas sampling and analysis at the stack

- **Environmental assessment**

This environmental assessment method allows comparing both pavement types (hot and warm) on an identical basis (i.e. same produced quantity, same pavement layer). The comparison between these cases was based on the following parameters: same mix design, paved on a same surface area and thickness, which corresponds to a given production of asphalt at a given void content. This comparative basis is referred to as the Functional Unit (FU) which was equal to the total asphalt mass to perform pavement maintenance for each road work whereas this FU is usually expressed as 1 ton of produced asphalt for hot mix plant production assessment. The selected environmental system is detailed in table 7. The present study focused on asphalt production and laying considering asphalt temperature as the main studied parameter.

Table 7: Functional Unit of the experiment (Asphalt Concrete mix design)

Process	HMA	WMA foamed NPG 35/50 bitumen	WMA special bitumen	WMA foamed special bitumen
Road works	Surface10 000m^2	Surface 10 000m^2	Surface 10 000m^2	Surface 10 000m^2
Plant	RAP: 278t New bitumen: 61,59t New aggregates: 1058t bitumen content: 5,40% asphalt to be produced: 1398t	RAP: 276t New bitumen: 61,68 t New aggregates: 1060t bitumen content: 5,40% asphalt to be produced: 1398t	RAP: 275t New bitumen: 61,74t New aggregates: 1061t bitumen content: 5,40% asphalt to be produced: 1398t	RAP: 278t New bitumen: 61,60t New aggregates: 1059 t bitumen content: 5,40% asphalt to be produced: 1398t
Transport	bitumen: 150km RAP: 0km asphalt: 30km aggregates: 0km	bitumen: 150km RAP: 0km asphalt: 30km aggregates : 0km	bitumen: 150km RAP : 0km asphalt: 30km aggregates : 0km	bitumen: 150km RAP s : 0km asphalt: 30km aggregates : 0km

Classical environmental indicators were calculated from environmental emissions, according to the following equation:

$$I = \sum_i \alpha_i . C_i . m_i$$

where I is the indicator of the examined impact category (e.g. greenhouse effect), α_i is the allocation coefficient (unitless) representing the percentage of compound *i* involved in the considered impact category, C_i is the contribution coefficient of 1 kg of compound *i* to the impact category, and m_i is the mass of compound *i* (kg). The computed indicators have been extracted from [5]: Global Warming Potential (GWP).

Data measured both at the plant and on the worksite were inputted into an environmental assessment method based on LCA. The measured data were then completed with data from the literature, for parts of the system that did not undergo measurements. Such was the case for airborne emissions due to engine exhaust from road works equipment and transport trucks. Truck engine fuel consumption figures were extracted from [7], while data on equipment engines were extrapolated from previous measurements. Airborne emissions were then calculated from consumption values in accordance with a French standard [8]. As for transport the data are provided by FD P 01-015 standard [8] while for roadworks engines

- **Experiments & results**

As indicated before, it has been decided to focus in the indicators whose environmental impact is global, regardless of the place where the contaminant is issued, the GWP and the energy consumption (EE). A comparison will also be made between the different configurations regarding the emissions measured at the stack and with the confined test.
These indicators have been calculated for the different phases of the LCA : bitumen production and transport, aggregates production and transport, asphalt mix production, asphalt transportation, road construction. The global impact of these different phases are summarized on the figure 6.

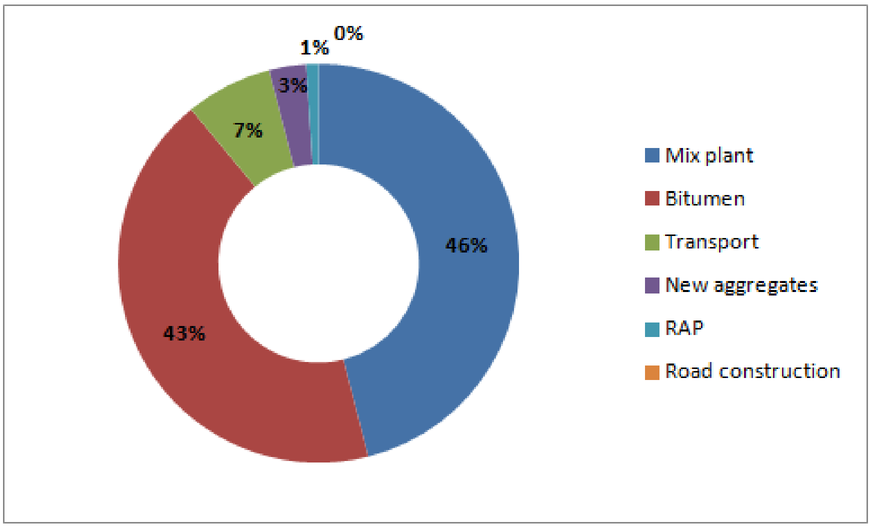


Figure 6: Global impact of LCA

As we can see, the biggest impact is the asphalt production at the mix plant. Moreover, for the different configuration tested the impacts of the other phases of the LCA are identical or very similar. Consequently the results below only focus on the impacts generated at the mixing plant.

The average temperatures of production are the following ones: 169 °C for HMA, 142 °C to WMA with foamed binder, 139 °C for WMA with special binder, and 139 °C for WMA with foamed special binder.

Only the results of two out of the 3 WMA technologies are shown the results obtained for the section 1, using WMA with foamed binder seem not consistent with those of the other sections and of previous studies. To better understand this point, additional laboratory tests are planned.

For both indicators there is a small gap between the HMA and WMA. This can be explained in part by the low production temperature difference (hot / warm) on average. The GWP and the Energy Equivalent (EE) are shown in figure 7 below.

A selection in the data was made to get phases where production temperatures were stabilized, so as to emphasize the temperature differences between HMA and WMA; the average temperatures of these stabilized phases are respectively:

- HMA: 166 °C
- WMA with special binder: 134 °C
- WMA with foamed special binder: 134 °C

The figure 7 shows the results for the 2 indicators, following these new cuts. Globally, the positive effect of WMA is confirmed.

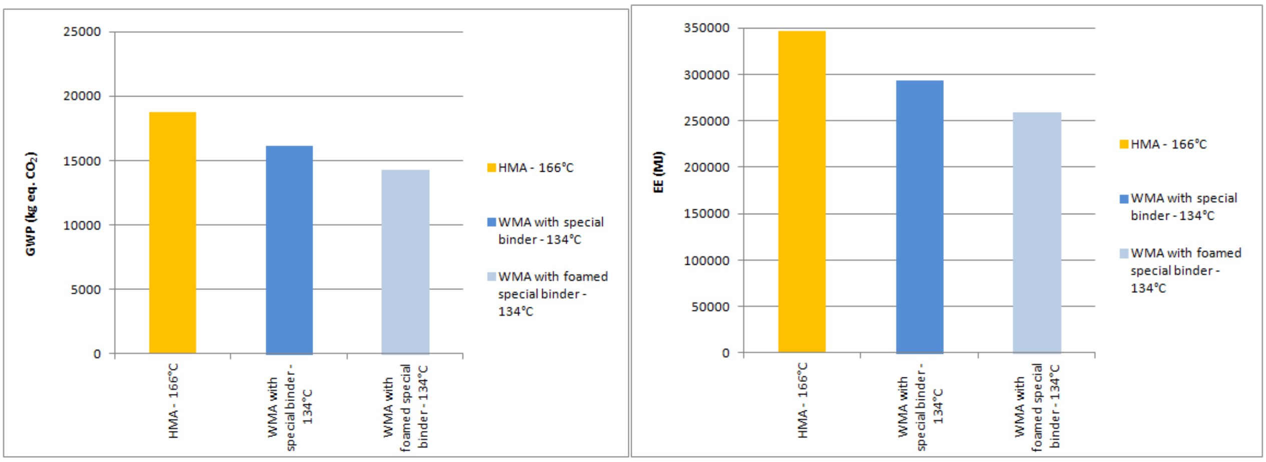


Figure 7: GWP and EE indicator after cutting

4. CONCLUSION

A comparative study of different WMA technologies was carried out through an innovative partnership involving a leading figure in the European construction, public works and concessions sector, a major player in the European research on the city and the territories, transportation and civil engineering, and, a leading international oil, gas and solar company.
This study looked at both the mechanical and the environmental performances of the 3 different WMA technologies comparatively to a traditional equivalent HMA.
The mechanical assessment was carried out through laboratory testings as well as on site measurements. The extensive laboratory evaluation seems to show that the 4 asphalt mix configurations tested lead to similar and very satisfying level of performances. The on-site measurements show some limited differences between the different sections as one of the WMA section is not as well compacted as the other ones probably due to the application conditions. Moreover the stiffness modulus measured on extracted cores is a bit higher for the HMA section compared to all the WMA sections. A follow-up of the evolution in time of the sections is planned and has already started.
Within the scope of this experiment, the warm mix process has been found to positively contribute to the reduction of all calculated indicators, in comparison with the hot-mix process, thereby confirming the findings from previous studies on energy savings predicted by theoretical models. This improvement proves to be especially significant with respect to Energy Consumption and Global Warming Potential. Some comparisons of the environmental impact of the different technologies have been presented and discussed but further study is necessary to better explain some of the data.

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