WARM ASPHALT MIXES MADE WITH A "READY TO USE" BITUMEN: AN EXPERIMENTAL FIELD TRIAL

Laurence Lapalu[1], Catherine Juery[1], Agnès Jullien[2], Philippe Tamagny[2]
[1]Total Raffinage Marketing
[2]IFSTTAR de Nantes

ABSTRACT

Within the framework of the Conference of the Environment, the French road companies signed an agreement of voluntary commitment in which they make in particular a commitment to reduce greenhouse gas emissions of the order of 33 % to the horizon 2020. We worked on the formulation of a "ready to use" binder to formulate warm mixes at 120°C, with mechanical performances comparable to those of the hot mixes. An experimental trial was realized in 2009 in association with the IFSTTAR of Nantes, the Regional Laboratory of the Department of civil engineering (LRPC) of Blois and the General Council of Loir-et-Cher. The objective of this test was to make and to apply warm and hot mixes to compare the both techniques. Environmental measurements were also realized at the mixing plant and showed a gain of the order of 30 % on greenhouse gas emissions. The mechanical tests realized by the Regional Laboratory of the Department of civil engineering confirmed that the warm and hot mixes made at the mixing plant display comparable mechanical characteristics. After one year of service, the sections realized with warm and hot mixes present no degradation. A follow-up of this experimental trial will be realized during 3 years.

Keywords: warm asphalt mixes, ready to use bitumen, experimental trial, environmental measurements

1. INTRODUCTION

At present, one of the key challenges is to concentrate on saving natural resources for future generations while bringing industrial activities into a more stable long-term balance between environmental preservation and costs. According to the World Health Organization [1], clean air is now recognized as a basic requirement for human health and well-being. Moreover, some countries have been continuously working since the 1992 Rio Conference to reduce the airborne emissions produced by engineering processes.
The warm mix asphalts (WMA) are a relatively recent technique, developed in response to the needs of the road industry of decreasing the energy consumptions, the emissions and the workers exposure. Studies carried out in Europe and in the United States show that these techniques indeed allow to reduce the energy consumption until 35 % and to reduce CO_2 emissions until 40 % [2] [3]. 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), in which they make in particular a commitment to reduce greenhouse gas emissions of the order of 33 % to the horizon 2020 [4].
In this context, TOTAL developed a "ready to use" formulation of bitumen to allow our customers to produce and to apply WMA at 40°C lower than HMA, without modification on their power plants and on their equipments of application. The technical feasibility of this new technology was assessed during an experimental test in September-October 2009. This experimental trial was realized in association with the IFSTTAR of Nantes, the Regional Laboratory of the Department of Civil Engineering (LRPC) of Blois and the General Council of Loir-et-Cher. We made and applied hot mix asphalts (HMA) and WMA to compare the both techniques, in terms of energy consumptions, reduction of emissions and performances.
Besides, this job site is the object of an annual follow-up by the LRPC of Blois to assess the evolution of sections realized with WMA compared with HMA reference sections.

2. EXPERIMENTAL

2.1 Materials

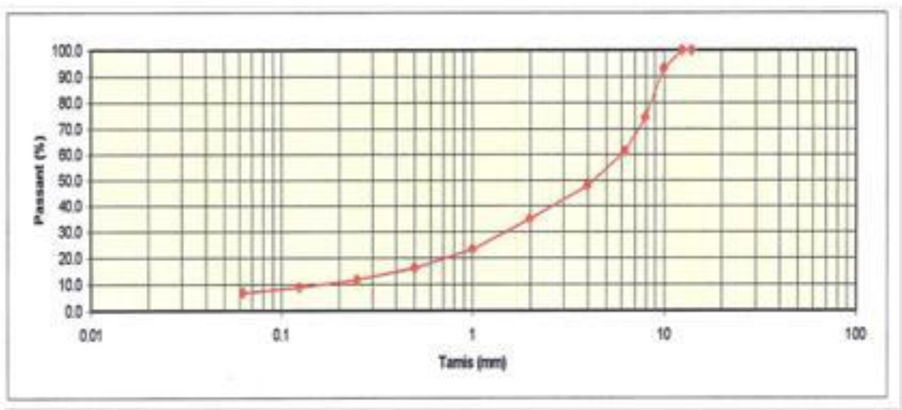
Two bitumens were used for the experimental trial : a conventional 35/50 bitumen obtained from a TOTAL refinery for the hot mix asphalt (HMA) and a "ready-to-use" bitumen (LT bitumen) for the manufacturing of the warm mix asphalt (WMA). The penetration at 25°C and the softening point of the different binders are listed in Table 1.

Table 1 : Characteristics of the bitumens.

		Bitumen 35/50	LT bitumen
Penetration at 25°C (1/10 mm)	NF EN 1426	41	38
Softening point (°C)	NF EN 1427	52.6	52.9

The applied mixes are EB 10 (BBSG 2 0/10) as defined in the European Standard NF EN 13108-1. . The curve of the mixes granulometry is displayed in Graph 1.

Graph 1 : Curve of the granulometry of the mixes EB10 (bitumen content : 5.2%).

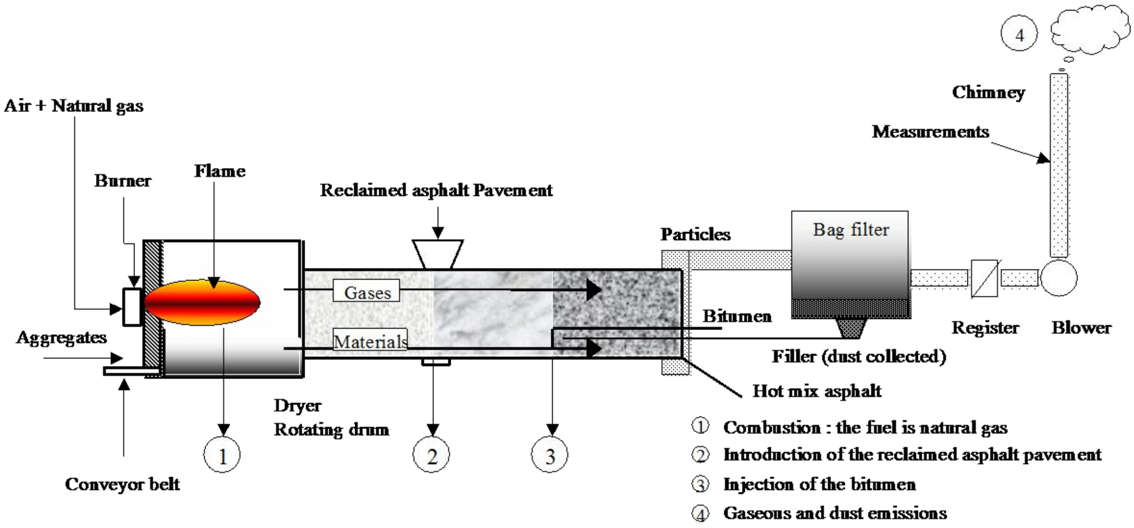


2.2 Environmental measurements

Hot mix plant and roadworks

The HMA plant in Blois (TSM 17), supplied with natural gas, is a hot-mix drum operated by means of parallel flow, according to which aggregates flow in the same direction as the gas(see Figure. 1).

Figure 1 : Scheme of a Drum Mix HMA Plant process



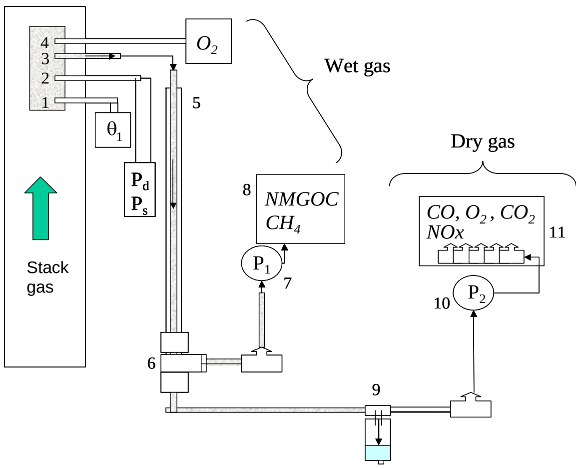
The warming and drying of aggregates is performed by introducing aggregates into the upper part of the drum using the main conveyor belt. Each granular class is stored inside a separate hopper, which then feeds the main conveyor belt via the largest secondary belt. The bitumen is put into the remaining half of the drum. At the dryer entrance, new aggregates and/or reclaimed asphalt pavement mass flows are continuously measured. Gas consumption is controlled by the position of a gas feed lever, which may be varied (i.e. either open or closed). This information is not calibrated, and an increase in supply value serves to increase consumption. Total gas volume (volume of the natural gas burned + water vapor of the drum + excess air burned) is discharged into the atmosphere by an extractor operating at a fixed velocity. Under normal operating conditions, since total gas volume changes with operating conditions, the operator acts upon the gas control level in order to: i) modulate pressure head loss, and ii) continuously manage gas flow variations. The information available for monitoring thus consists of the position of this extractor-regulating device; such information is not calibrated when using volume units, such that it varies between zero (maximum additional head loss) to 100 (head loss completely removed). The fan extracting air from the dryer places the entire drying system in a state of depression.
A computer sets the production rate, the corresponding flows of granular materials for each hopper and the bitumen amount, all as a function of: i) the required mix design, ii) the eventual use of recycled asphalt pavement, and iii) the moisture content of all granular materials. The operator then checks the entire installation in the aim of keeping constant the various parameters, i.e.: i) asphalt temperature, which ensures both the mechanical homogeneity of products and compliance with standards; and ii) vacuum pressure at the burner head, which ensures the proper discharge of gas produced by the burner flame and water vapor released from dried aggregates.
The studied pavement is the wearing course (6cm thick, 7.5 m width, 1km length) for RD 957 near Blois (France). Half pavement is made of hot-mix asphalt, the other with lower temperature asphalt. For the environmental assessment and the experimental campaign, the bitumen rate is of 5.21 and the functional unit defined according to LCA framework is finally of 750 m2. Finally 535.5 tons of asphalt (BBSG 0/10) is produced for this experiment.

Data collection and measurement campaign

At the plant (Figure 1), gas and electricity consumption were measured along with airborne emissions, volume fractions of O_2, CO_2, NOx, 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 (i).
An automatic weather station also monitored ambient pressure and temperature, as well as atmospheric humidity. These parameters are necessary for the conversion of pollutant volume fractions into mass flows (i). The sampling and measurement principles at the main stack are presented in Figure 2. To avoid any compound condensation, the sampling device was heated to 180°C, from the sampling probe (No. 3) to the chemical analysis apparatus located at the bottom

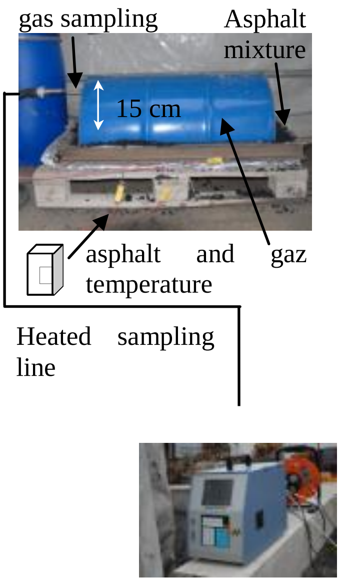
of the stack (Nos. 8 and 11). Secondary stack emissions were sampled using the same kind of probe and line as for the main stack. The heated line was directly connected to the FID analyzer.
At the roadwork site, the operating times for each machine (compactor and finisher) were measured in order to estimate machine energy consumption and emissions. An experimental device dedicated to GOC emission measurements on hot or half-warm asphalt was also installed at the mixing plant. A quantification of diffuse emissions due to asphalt during the lay down stage is hardly feasible at the site because of compactors constantly moving in and out; this evaluation step was therefore performed at the plant using a gas chamber, as shown in Figure 3. This method has already been fully described in [5].

Figure 2 : Principles of gas sampling and analysis at the main stack



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 3: Confined test principle using the flux chamber (assessment of GOC emission potential during lay down stage)

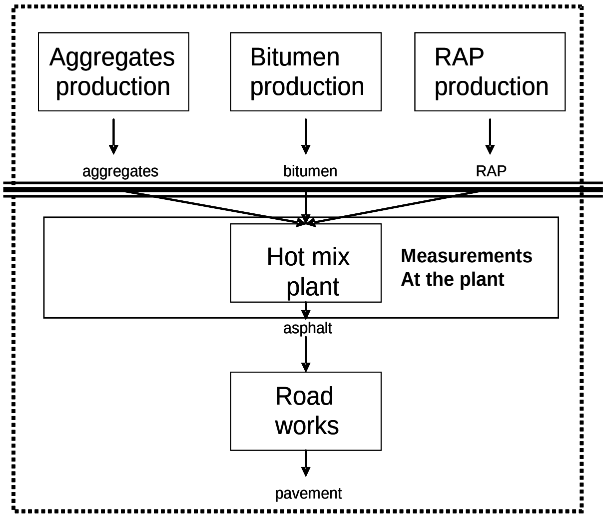


As for transport the data are provided by Hugrel et Joumard [6], while for roadworks engines, they are obtained from FD P 01-015 standard [7].

Environmental assessment

Data measured both at the plant and on the worksite were inputted into an environmental assessment method based on a LCA based methodology and already performed before [8], The measured specific data concerning asphalt mixing processes, are usually 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 [9], while data on equipment engines were extrapolated from previous measurements [9]. Airborne emissions were then calculated from consumption values in accordance with a methodology previously published [10].
This environmental assessment method allows comparing both pavement types (hot and half-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 depicted in Figure 4 with comments on data included in the assessment. The present study focused on asphalt production and laying considering asphalt temperature as the main studied parameter.

Figure 4 : General environmental system (Ventura et al, 2009)



(a) 0% of RAP in this study

Process	Rationale
Crude oil extraction, transport and refining	Amounts and origins of materials identical, not considered. No RAP in this experiment.
Aggregate extraction and transport	
Additive production and transport	Lack of available validated data, not considered
Energy production and transport	Upstream processes, not considered.
Equipment production and wear	Same equipment for both asphalts, differences are assumed negligible
Waste and water treatment	Amounts and nature assumed identical

(b) system boundaries

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 classification coefficient (unitless) representing the percentage of compound *i* involved in the considered impact category, C_i is the characterisation 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 (ii): Global Warming Potential (GWP), Acidification Potential (AP), Photochemical Ozone Creation Potential (POCP), and Eutrophication Index (EI). For compounds included in several impact categories, the rules have been adopted in general for the classification coefficients according to the whole system given in Figure 4 are discussed in [8].
The methodology implemented to calculate mass flows depends on analyzer type, as explained in [10]. The coefficients are given in Table 2.

Table 2 :coefficients for the indicators calculation.

Indicator	Process	SO_2	CO	NOx	CH_4	CO_2	NMGOC
POCP	Contribution Coef	0.048	0.027	0.028	0.007	0	0.416
	Hot mix plant	0.5	1	0.5	0.5	***	1
	Road work	0	0	0	0.5	***	1
	Transports	0.25	0.5	0.25	0.5	***	1
AP	Contribution Coef	1	0	0.695	0	0	0
	Hot mix plant	0.5	***	0.5	***	***	***
	Road work	0	***	0	***	***	***
	Transports	0.25	***	0.25	***	***	***
EI	Contribution Coef	0	0	0.13	0	0	0
	Hot mix plant	***	***	0.25	***	***	***
	Road work	***	***	0	***	***	***
	Transports	***	***	0.125	***	***	***
GWP	Contribution Coef	0	0	0	25	1	0
	Hot mix plant	***	***	***	1	1	***
	Road work	***	***	***	1	1	***
	Transports	***	***	***	1	1	***

3. RESULTS AND DISCUSSION

3.1 Mixes production at the industrial scale

The mixes were manufactured at the plant of the General Council of Loir et Cher, in the city of Blois. The road trial has taken place over three days from September 29th to October 1st. 500 tons of WMA were produced on September 29th afternoon and on September 30th morning. 500 tons of HMA were manufacturing on the September 30th afternoon and on the October 1st. The objective was to test the technology under different conditions, cold in the morning and hot in the afternoon.
The HMA were manufacturing with aggregates at 170 °C and bitumen 35/50 at 160°C. The production rate was set to 150 t/h which is the regular rate for this plant. The burner was set to 57% of its maximal power, the regular setting. No problem was recorded, the mixing was good : no uncoated aggregates were observed. The temperature of the mix was 170°C. Very little fumes and steam could be observed at the plant chimney. The fumes temperature was about 140°C. The smell of the hot bitumen was noticeable.
At the beginning (1st truck), the WMA were produced with the LT bitumen at 150°C and aggregates at 140°C. The aggregates temperature was progressively decreased from 140°C (1st truck) to 122°C (3rd truck) and was then kept constant between 122°C and 125°C without any problem. The production rate was set to 160 t/h, which is slightly higher than the normal rate. The reason of this adjustment is that the burner was set to the minimal power and could not be reduced further. In order to adjust the temperature to 120°C, under dry conditions, the only solution was to increase slightly the production rate. The mix quality was good, we observed no uncoated aggregates. Very little fumes could be observed at the plant chimney. The fumes temperature was quite cold, close to 100°C, which could induce a risk of clogging the dust filter at the chimney base. The clogging of the filter was not observed during this trial. The smell of the LT bitumen was unnoticeable.

3.2 Mixes characterization

We took samples of HMA and WMA in the trucks for characterization in the laboratory. The tests were carried out immediately after the sampling.
The mix characterization was made by the Regional Laboratory of the Department of Civil Engineering (LRPC) of Blois. The characteristics of the mixes are listed in Table 3. The percentage of voids and the rutting resistance of the HMA and the WMA are similar. The ratio r_{water}/R_{air} of the WMA is slightly lower, due to a lower compression resistance after immersion in water. In both cases, the characteristics of the mixes complied with the European specifications of a mix EB10 (BBSG 2 0/10).

Table 3 : Characteristics of the HMA and WMA produced in the plant. Measurements realized by the LRPC of Blois.

		Hot mix 165°C	Warm mix 120°C	Specifications EB 10 (BBSG2 0/10) NF EN 13108-1
Gyratory compactor method Voids content at 60 gyrations	NF EN 12697-31	7.8	8	$5 \leq V_{60} \leq 10$
Duriez test r_{water} (MPa) R_{air} (MPa) r_{water} / R_{air}	NF P98-251-1	 10.31 10.99 0.94	 9.90 12.27 0.81	 ≥ 0.75
Rutting depth at 60°C after 30000 cycles (%)	NF EN 12697-22	5.1	4.8	≤ 7.5

3.3 Pavement laying and compaction

The trial took place between Blois and Vendôme, at around 30 minutes of transport from the plant. The road RD957 is a four lanes road with a high traffic level (traffic T1).
The first test section was realized with the WMA on September 29th in the afternoon. The weather was sunny and dry and the temperature was 23°C. The section was uphill and then going downhill, exposed to sun. The mix from the first truck arrived at 130°C, which was normally because it was produced at 140°C. The temperature of the other trucks was quite constant 115-120°C. The finishers were heated at 130°C. There were two finishers, one on the slow lane, the other one on the rapid lane. The mix was laid and compacted between 115 and 105°C. The thickness of the mix was 6 cm. The compaction had been done using one tire-cylinder compactor (21t) and 2 small vibrating cylinder compactors for all the mixes. The mix behaved normally during the whole process, we observed no problem during the laying and the compaction (Picture 1). The second test section was realized with the WMA on September 30th in the morning. The weather was sunny but cold, 9°C and windy. The section was going downhill. The mix was laid and compacted in the same conditions as the day before. During the compaction process of the first meters, sticking on the compactor wheels occurred, which slowed down the work. Indeed, the paving equipment had cooled down over night and so was cold at the beginning of the trial. However, clear advantages of the WMA technology were confirmed by the experiment. The workers work more comfortably as they feel less heat from the pavement, especially on September 29th in the afternoon. Moreover, the working temperature reduction suppresses the smell at the mixing plant and on the job site too.
The third section was realized with HMA on September 30th in the afternoon. The weather was sunny and the temperature was 25°C. The fourth and last section was realized with the HMA too on October 1st in the morning. The weather was cloudy and mild, 15°C. The mixes were laid and compacted at 160°C without any problem, in both cases. No sticking on the wheels could be observed, even though the equipment had cooled down over night. On the other hand, the smell of the bitumen was clearly more present than during the laying of the WMA. The sensation of heat was also very intense, especially on September 30th in the afternoon.

Picture 1 : Implementation of the WMA.

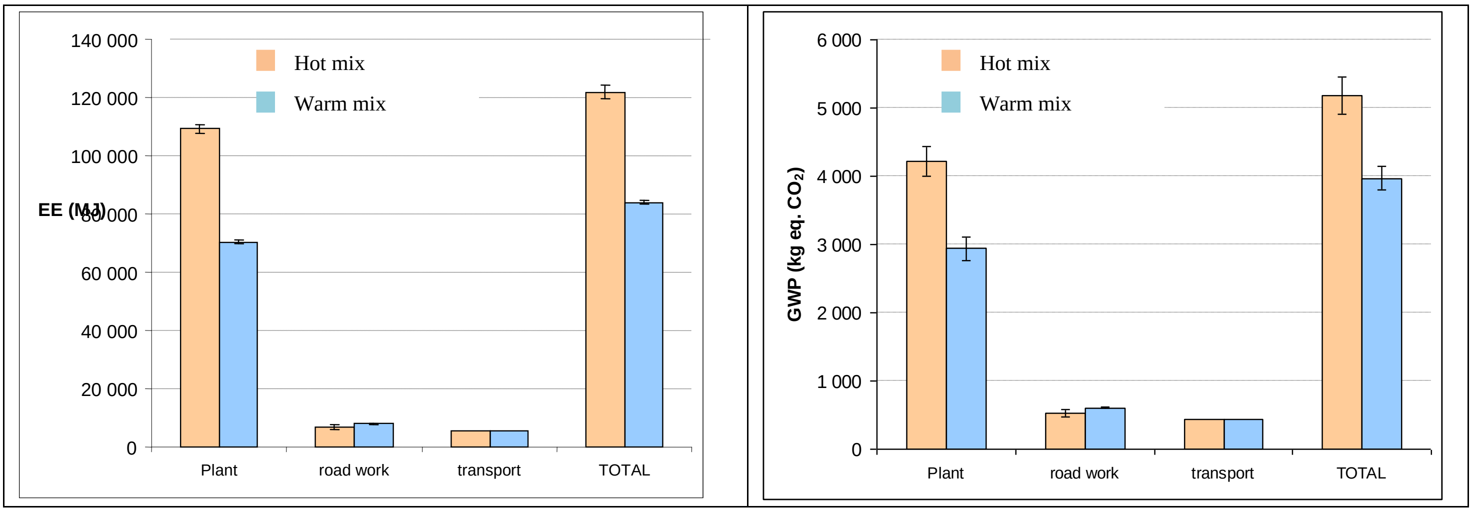
3.4 Environmental measurements

Table 4 gathers the experimental flux obtained from this experiments and compares hot and warm asphalt. The resources consumption is reminded in Table 4 at the bottom for the sake of comparisons. To better show the difference between the two studied asphalt, Figure 5 shows the compared energy consumed and Global Warming Potential (GWP) calculated. This campaign shows the significant reduction in energy consumption as well as of GWP. The differences at the road work sites are very small to be negligible between hot and warm asphalt. More the value of corresponding impacts are small too, with respect with the hot-mix plant contributions. The road works GWP and energy consumption are found to be equivalent to the transport between the plant and the road site. The type of trend is also noticed for other indicators when determined with significant decrease of impacts between hot and warm techniques (greater than 20%).

Table 4 . LCI for considered pollutants, the plant-road work distance is of 10 km.

			Plant		Road works		Transports (10 km)
FLUX		UNIT	hot	warm	hot	warm	
Energy	natural gas total	MJ/UF	107 012	68 541	***	***	***
	Diesel fuel	MJ/UF	***	***	6 942	7 948	5 656
	electricity	MJ/UF	2 273	1 858	***	***	***
emissions to air	CO_2	kg/UF	4 215	2 621	506	579	411,94
	CO		92,35	10,38	1,40	1,61	1,14
	NMCOG		5,35	6,20	0,35	0,41	0,53
	NOx		2,43	0,87	6,45	7,38	5,25
	CH_4		0,13	12,70	***	***	***
	SO_2		5,10	2,76	***	***	***
	dust		***	***	0,35	0,41	0,29
	N_2O		***	***	0,07	0,08	0,06
Resources	water	l/UF	***	***	93	110	
	aggregates	t/UF	507.6	507.6	***	***	
	bitumen	t/UF	27.9	27.9	***	***	
	asphalt	t/UF	535.5	535.5	***	***	

Figure 5 : Global results for this experiments.



3.5 Follow-up of the trial

The Regional Laboratory of the department of Civil Engineering (LRPC) of Blois is in charge of the follow-up of this experimental trial since the application and for a duration of three years, until October, 2012.

The Measurements of the mixes compacity were realized on the job site, by using a Gamma densimeter Mobile with Variable Depth (GMPV), on the fast and the slow lanes, a few months after the implementation. The values of the compacity are displayed on the Figure 6. They are very satisfactory and are equivalent for the HMA and WMA, on the driving and the passing lanes.

The LRPC realized measurements of the transverse deformations and the evolution of the macrotexture, before, after the works and after 1 year of service of the road.

The measurements of the transverse deformations and the characteristic rutting were realized by means of Transversoprofilometer with ultrasounds (TUS) on the slow lane (Figure 7). The values are very low and confirm on the one hand the good quality of the support and on the other hand the improvement brought by the implementation of a mix EB 10 (BBSG 2 0/10).

The measurements of the macrotexture were made by using a Rugolaser 2, on the fast and on the slow lanes, in the axis and on the right-hand side of every lane (Figure 8). The values can be compared just after the works and after 1 year of service, on the fast and on the slow lanes, in HMA and in WMA. The observed variations are low and confirm the good performances of the both sections, in WMA and HMA.

In conclusion, the controls made on the road are satisfactory after one year of service of the road. Besides, no degradation was visually observed. The effective decrease of 40°C of the manufacturing and the application temperature of the WMA made with the LT bitumen does not damage the mechanical performances of the road. The follow-up over 3 years of the job site will allow ending on the durability of the WMA subjected to the climatic variations and to the normal attacks of the traffic.

Figure 6 : Values of the mixes compacity, measured by using a Gammadensimeter Mobile with Variable Depth.

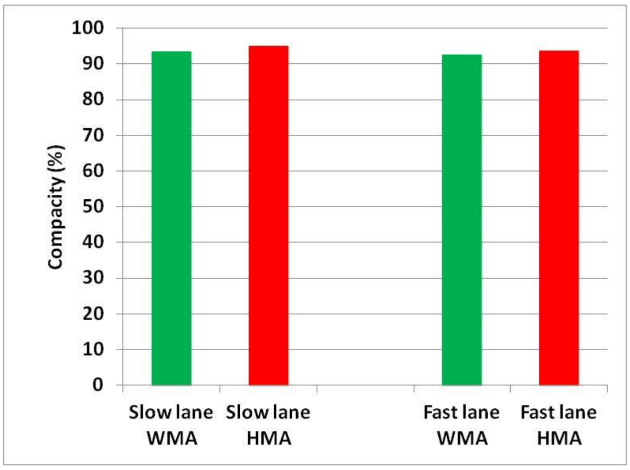


Figure 7: Measurements of the transverse deformations and the rutting on the slow lane, before the works and after 1 year of service. The results are expressed in total deformation in mm, corresponding to all the lane width and in rutting depth of the driving lane.

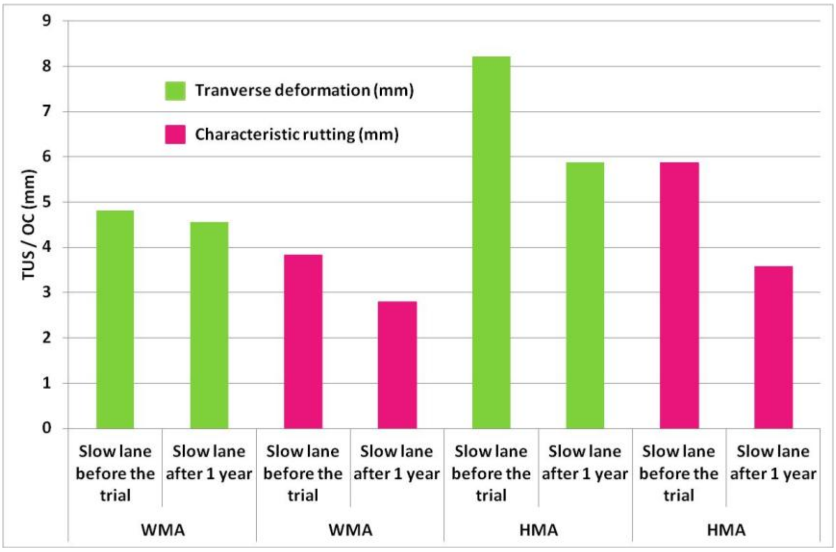


Figure 8 : Macrotexture measurements using a Rugolaser 2.

4. CONCLUSION

The warm mix asphalt (WMA) technology using the "ready to use" bitumen was validated at the industrial scale. The WMA were consistently produced between 122 and 125°C, laid at 110°C and compacted at 105°C.
Minor difficulties appeared in relation to the use of WMA. The workers had more difficulties to handle the mixes manually. Moreover, the power of the burner of the mixing plant must be reduced to its minimum which induces more difficulty to adjust the production temperature. The fumes and dust generated in the plant are cooler which induces a higher risk to clog the dust collector filter on the long term (need for regular control), especially in case of wet aggregates. Moreover, under cold conditions, some sticking on the finisher and compactor wheels can occur.
Besides, clear advantages of the technology were confirmed by the experiment. The delivery of a “ready to use” binder was very much appreciated by the user, along with the fact that no major adjustment of the production and paving equipments was required. Workers work more comfortably as they feel less heat from the pavement. The use of the low-temperature technology suppresses the smell at the mixing plant and the job site.
Moreover, the production capacity of the plant was not reduced. The technology was tested under different conditions of ambient temperatures, cold in the morning and hot in the afternoon and was implemented successfully in all cases.
Within the scope of this experiment, the warm has been found to positively contribute to the reduction of all calculated indicators, in comparison with the hot-mix process. This improvement proves to be especially significant with respect to Energy Consumption, Global Warming Potential, eutrophication, acidification, Photochemical Ozone Creation.
Finally, he follow-up over 3 years of the job site will allow ending on the durability of the WMA subjected to the climatic variations and to the normal attacks of the traffic.

ACKNOWLEDGEMENT

The authors would like to thank Mr Lapeyre, Mr Breton and Mr Moulin, of the LRPC of Blois, and Miss Lachet of the General Council of Loir et Cher for their helpful contribution. The authors thank all the team of LCPC-DDGC who performed the experiments; LCPC merged with INRETS on the 1st of January 2011 to create Ifsttar French institute of science and technology for transport, development and networks.

REFERENCES

[1] WHO (World Health Organization), 1999. Air Quality Guidelines for Europe. WHO Regional Publications, European Series. In: World Health Organization Regional Publications European series (Ed.), Copenhagen, Denmark, 91 : 1-41.

[2] Warm mix asphalt : European Practice. February 2008. Washington D.C. : Federal Highway Administration (FHWA-PL-08-007).

[3] Hurley G.C., Prowell, B.D., Evaluation of potential processes for use in warm mix asphalt, Journal of the Association of Asphalt Paving Technologists, vol. 75, pages 41-85.

[4] Convention d'Engagement Volontaire des acteurs de conception, réalisation et maintenance des infrastructures routières, voirie et espace public urbain, Paris, 25 mars 2009.

[5] Jullien A., Moneron P., Quaranta G., Gaillard D. (2006b) A study on air emissions from pavement layings made of different reclaimed asphalt rates”. Resources, conservation and recycling, Vol47, pp 356-374.

[6] Hugrel C. and Joumard R. (2006) Directives et facteurs agrégés d'émission des véhicules routiers en France de 1970 à 2025, Rapport LTE n°0611 de l'Institut National de Recherche sur les Transports et leur Sécurité (INRETS).

[7] FD P01015 Standard (2006) Qualité environnementale des produits de construction – Fascicule de données énergie et transport.

[8] Sayagh S., Ventura A., Hoang T., François D., Jullien A., 2010. Sensitivity of the LCA allocation procedure for BFS recycled into pavement structures, Resources Conservation and Recycling, Vol. 54, pp. 348-358.

[9] Jullien A., Monéron P, Ventura A, Legret M, Demare D, De la Roche Ch, Schemid M, Lachet C, Gaillard D, Oudin J, Jacques J-P, Meriel B, Boittin R, Cabannes H, Jumontier Ph, Seytre S, Lacoste K, Wendling L, Bernard M „"Analyse de Cycle de Vie appliquée à un chantier d'entretien routier sur la RN 76-Evaluation technique et environnementale d'une couche de liaison d'enrobé bitumineux pour différents taux de recyclage », collection ERLPC, 2005,225 pages.

[10] Paranhos, R., Ventura, A., Monéron, P. & Jullien, A. (2005) Smoke-stack airborne emissions of a hot mix asphalt plant for life cycle inventory available data. 2nd International Conference on Green and Sustainable Chemistry of American Chemical Society, Washington DC (USA), June 20-24, 2005.