DEVELOPMENT OF A READY TO USE LOW TEMPERATURE BINDER AT THE INDUSTRIAL SCALE

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ABSTRACT

Fossil fuel savings and reducing greenhouse gas (GHG) emissions are one of the main challenges of our Society.
Since most of the fuel consumed in the manufacture of Bituminous Hot Mixes is mainly linked to the heating of the aggregates, a reduction in the manufacture temperatures means a reduction in fuel consumption, a diminishing in CO_2 *emissions and important economical savings.*
In this context a ready to use low temperature binder has been developed. The use of this binder in the manufacture of warm bituminous mixes allows temperature reductions up to 40 ºC with fuel savings around 25 %, and reductions in CO_2 *emissions up to 24 %.*
The results of two different test trials carried out in France (Rennes) and in Spain (Valladolid) with such binder, are stated in this paper. An exhaustive study, prior to the implementation, has been carried out at the laboratory. In addition a complete monitoring of the manufacture and laying of the mixes, including gas emissions measurements and mix performance, have been completed.
Preliminary results have sustained fuel savings and emission reductions with the same performance of a hot bituminous mix.

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

1. INTRODUCTION

The warm mix asphalts (WMA) are a relatively recent technique, developed in response to the needs of the road industry for decreasing energy consumptions, emissions and 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 % [1] [2].
In France, the main actors of the road infrastructures market signed in March 2009 an agreement of voluntary commitment with the Ministry of Ecology, Energy, Sustainable Development and the Town and Country Planning (MEEDDAT), compromising themselves to reduce greenhouse gas emissions in a 33 % by 2020 [3].
In this context a "ready to use" formulation of bitumen has been developed to allow our customers to produce and to apply WMA at 40°C lower than hot mix asphalts (HMA), without any modification on their asphalt plants and on their equipments of application.
The results of two different test trials carried out in France and in Spain with such binder, are stated in this paper. An exhaustive study, prior to the implementation, has been carried out at the laboratory. In addition a complete monitoring of the manufacture and laying of the mixes, including gas emissions measurements and mix performance, have been completed.

2. TEST TRIAL IN FRANCE

After a first field trial of the Low Temperature Bitumen (LTB) in Blois in September 2009 [4], we organized a second one in order to improve our knowledge and our experience about the warm mix asphalts technology. The main aim of this second trial was to test the ability of LT bitumen to ensure a good coating of the aggregates at 120°C and a good compaction of the mix between 100 and 110°C. This trial was also the occasion to evaluate the limit of our technology by testing several variant parameters, especially the application of a warm base course and the use of reclaimed asphalt pavements (RAP) in the warm mixes.

2.1 Materials

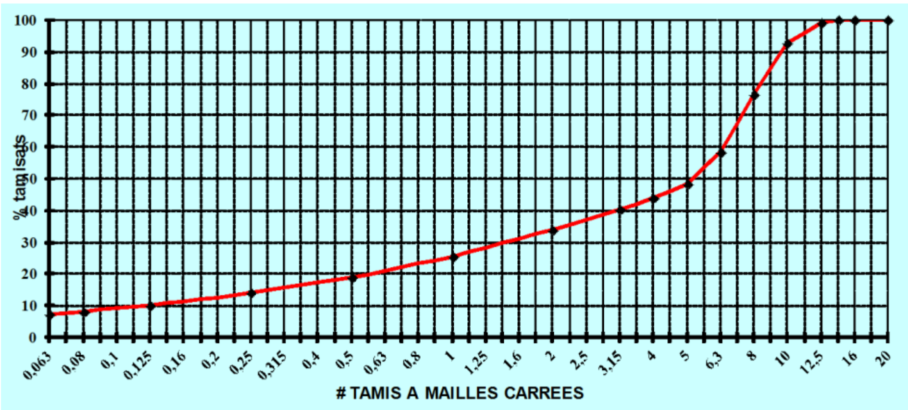
A "ready-to-use" Low Temperature Bitumen (LTB) was used for the experimental trial for the manufacturing of warm mix asphalts (WMA). A conventional pure bitumen B 35/50 was used for the laboratory tests, to make HMA. The penetration at 25°C and the softening point values of the binders are listed in Table 1.

Table 1 : Characteristics of the binders.

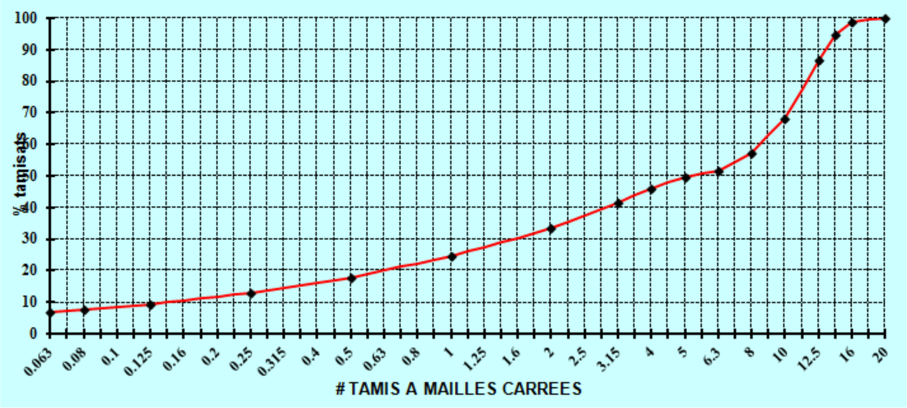
		35/50	LTB
Penetration at 25°C (1/10 mm)	NF EN 1426	38	42
Softening point (°C)	NF EN 1427	52.4	51.0

The applied mixes are EB 14 (GB 0/14) and EB 10 (BBSG 0/10) as defined in the European Standard NF EN 13108-1. The curves of the mixes granulometry are displayed in Graphs 1 and 2.

Graph 1 : Curve of the granulometry of the mix EB10 (bitumen content : 5.5%).



Graph 2 : Curve of the granulometry of the mix EB14 (bitumen content : 4.9%).



2.2. Preliminary tests

Prior the field trial, the WMA were characterized in the laboratory. Their characteristics were compared to those of the HMA made with a conventional 35/50. Our experience of a previous trial showed that the rutting and the Duriez tests results were similar for HMA and WMA [4]. For this reason, we focused on fatigue and modulus measurements on the base course mix EB 14.

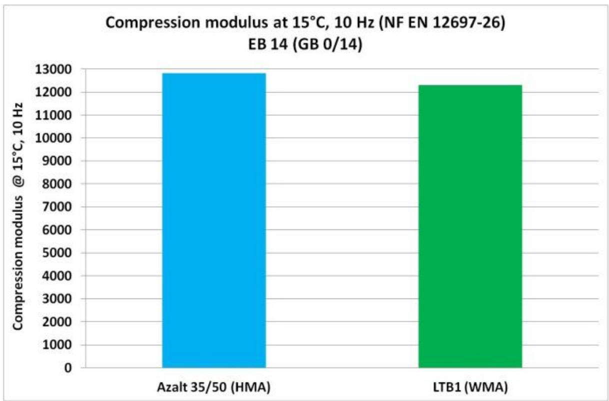
The WMA were made with aggregates at 120°C and the LTB at 165°C for the laboratory tests.

The characteristics of fatigue and modulus, measured for the mix EB 14 are displayed on the Graphs 3 and 4.

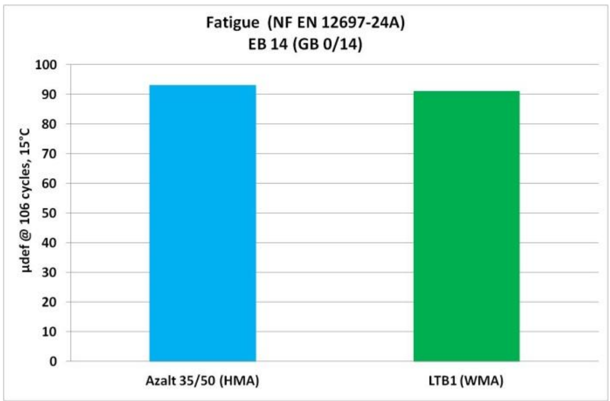
The modulus measurements were carried out at 15°C and 10Hz by using the direct traction method on cylindrical geometry. The value obtained for the WMA is slightly lower than that of the HMA but still complying with the specification of the European standard (Graph 3).

The fatigue resistance has been measured using the two points flexion method on trapezoidal samples. The Graph 4 represents the fatigue resistance for the WMA and the HMA. As well as for the modulus, the value measured for the WMA is slightly lower than that of the HMA but still complying with the specifications defined in the European standard NF EN 13108-1. Taking into account the precision of these measurements, the differences of the fatigue and modulus values between HMA and WMA were not significant and these warm mixes formulations has been considered as validated in the laboratory and ready to be applied on the field.

Graph 3 : Compression modulus for the hot and Warm EB 14 - NF EN 12697-26



Graph 4 : Fatigue test for the hot and warm EB 14 NF EN 12697-24A1



2.3. Mix production and pavement laying

The mixes were manufactured at the mixing plant of a customer. The trial took place over two days from April 7th to April 8th in a warehouse, close to the city of Rennes, in Brittany. Around 950 tons of WMA were applied on different sections: a wearing course for a private individual parking area and a base course and a wearing course for heavy truck access.

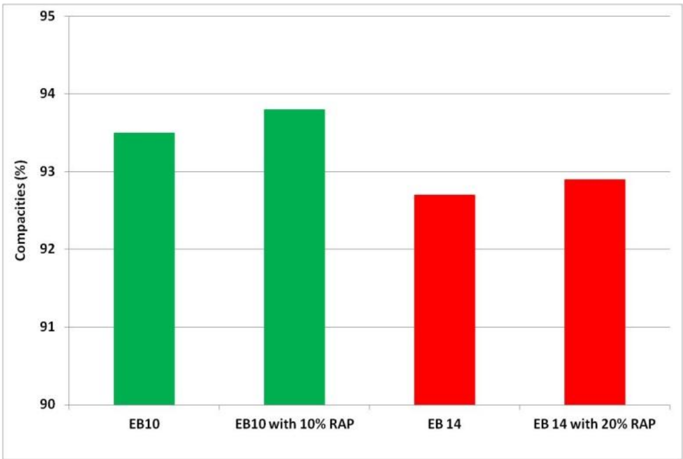
The first day, the WMA were manufactured at 120°C with aggregates at 120°C and the "ready-to-use" LTB at 145°C. The total quantity of mixes was approximately 470 tons. The plant production was set to 110-120 t/h and the power of the burner was adjusted between 56 and 60 % of its maximal power.

Mixes for the base course and the wearing course were manufactured respectively in the morning and in the afternoon. Manufacturing temperature of the WMA for the base course was varying in the beginning of production: 135°C for the

first truck, 110°C for the second and 125°C for the third truck. Then, the temperature was maintained at 125°C, with no problem detected at the level of the plant. We noticed the presence of badly coated aggregates for WMA manufactured at 110°C when loading the truck. WMA for the wearing course were manufactured in the afternoon at 125°C, without any problem. The customer was very satisfied with the coating quality of the aggregates because they usually have some coating problems even with HMA.
The temperature of the fumes was quite cool, closed to 105°C, which could induce a higher risk of clogging the dust filter at the base of the chimney. This problem was not observed during the two days of the trial. The smell of the bitumen was unnoticeable during the manufacturing of the WMA. During the phase of production, the customer recorded a decrease of 20 % on his consumption of fuel oil in the plant in comparison with the production of hot mix asphalts.
There was around 30 minutes of transport between the plant and the field. The weather was cold, 10°C, windy and cloudy. The WMA of the base course were laid in a part of the heavy truck access in front of the customer warehouse. The thickness of the base course was 7 cm. The WMA of the wearing course were used equally for the private individual parking area and for the heavy truck access area. A tack coat emulsion was spread on the base course before applying the wearing course. In both cases, the thickness of the wearing course was 6 cm. The asphalt mixes looked homogeneous and behaved normally during the whole process, for the base course mixes and for the wearing course mixes. No adaptation of the paver finisher was required during the laying. The customer appreciated to be able to apply a base course in the morning and the wearing course at the top in the same day. Nevertheless, the WMA were generally more difficult to handle manually for the workers. Compacity measurements on WMA were performed directly on the pavements for the different sections. The compacities of the base course and the wearing course were respectively around 92% after 12 or 14 compaction passes and around 95% after 8 compaction passes. These compacities values are very satisfactory for these mixes formulations.
The second day, the mixes were produced using reclaimed asphalt pavements (RAP). We introduce respectively 10% and 20% in the wearing course and in the base course asphalt mixes. The total amount of the mixes was around 470 tons too. The production flow was set to 120-150 t/h and the burner was set to 80% of the maximum power. We were obliged to increase the power of the burner because the RAP materials were quite wet, around 5% of humidity. Concerning the base course asphalt mixes, the first batches were produced at 125°C and we noticed some non-coated aggregates balls, also due to the rough RAP. The other batches were produced at around 140°C in order to recycle a maximum quantity of "old binder" around the RAP materials and to get a better coating of the aggregates. As the day before, the smell of the bitumen was not noticeable and we observed no clogging of the dust filter even when temperature of the fumes remained quite cold.
On the field, the weather was sunny, dry and quite warm between 15 and 20°C. The base course and the wearing, containing RAP, were applied respectively at 130°C and 115°C. We observed no difference compared to the day before. The compacities were measured directly on the pavement using a gamma densimeter. The values are displayed in Graph 5. The values are satisfactory for all the mixes and slightly higher for the WMA containing RAP materials.

Picture 1 : Implementation of the WMA.

Graph 5 : % Compaction of the different WMA.



3. TEST TRIAL IN SPAIN

3.1. Materials

A "ready-to-use" low temperature 50/70 penetration bitumen has been used in the Spanish Trial. The binder complies with the specifications described in the EN 12591 for a paving grade B 50/70 (Table 3) and has no problem to comply with the CE market.

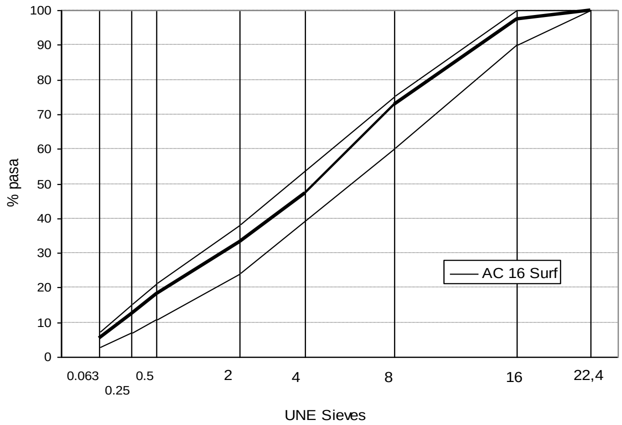
Table 3: Characteristics of the low temperature bitumen used in the Spanish trial.

Property	Test Method	Unit	B 50/70 LT
Original Binder			
Penetration, 25ºC	EN 1426	**0.1mm**	56
Penetration Index	EN 12591	**-**	-0.5
Softening Point	EN 1427	**ºC**	51.8
Fraass Breaking Point	EN 12593	**ºC**	-8
Flash point	EN ISO 2592	**ºC**	300
RTFOT Residue UNE EN 12607-1			
Change of Mass	EN 12607-1	**%**	0.32
Retained Penetration	EN 1426	**% p.o.**	57
Difference in Softening Point	EN 1427	**ºC**	7.7
Viscosity: 120 ºC	ASTM D 4402-87	**mPa/s**	1570
140 ºC			486
160ºC			199
180ºC			98

Previous tests and industrial trial were carried out on a semi-dense Asphalt Concrete designation AC 16S as described on the EN 13108-1 with the grading given on Figure 2. The aggregates used were silica origin and the binder content used changes between 4,8 % on the lab tests and the 5,0 % finally used in the road.

Table 4 and Graph 7: Mix formulation *(the aggregates are silica origin).*

UNE Sieve (mm)	% passing	
	S12 Envelope	RF
22	100	100
16	90-100	97
8	60-75	64
4	35-50	42.2
2	24-38	30.2
0.5	11-21	16.5
0.25	7-15	12.1
0.063	3-7	5.6



3.2. Preliminary tests

Prior to the implementation of the test trial in Valladolid, a study has been carried out at the laboratory to evaluate the performance of the LT binder and the mixes in which will be used.
Main studies has been based in the Marshall Test (EN 12697-30, 75 compaction blows) manufacturing mixes at different temperatures and with different binders (B 50/70 LT and a common B 50/70) and comparing mainly, density, void contents and stability.
Previous experiences on this test had shown that when compaction temperature is reduced density and stability values decrease dramatically. But on the other hand, the use of Low Temperature Binders reduced this falling obtaining values lower than those of the same mix manufactured at higher temperature but still on line with those expected for a hot mix asphalt [5].
Marshall compaction by repeated blow is clearly different from compaction on the field with compactors and rollers which kneads the mixture. Moreover, the Low Temperature Binder does not work by reducing viscosity but by decreasing the surface tension between binder and aggregates and the Marshall test conditions do not allow to underline that specific effect. For the WMA with the Low Temperature Binder, that could explain the difference between laboratory Marshall test and results on the field.
For the HMA reference, tests have been carried out with aggregates at 155 ºC and 130 ºC using standard bitumen B 50/70. For WMA Low temperature binder has been mixed with aggregates at 130 ºC. Both binders has been used at 155 ºC as they have similar viscosities. The results (Table 5) shown that a reduction of 21 ºC, using a Low Temperature Binder, leads to a density of 2.335 g/cm^3, more than 99 % of that obtained with a common 50/70 at a usual temperature and higher than that obtained with the common binder at the same temperature (98.5 %).
Regarding stability values a decrease of 18 ºC using the common 50/70 binder leads to values of 9.6 kN, 66.7 % of that obtained at 149 ºC (14.4 kN) and out of the range expected for a HMA. On the other hand the use of the low temperature binder leads to a value of 12.8 kN, more than the 90 % obtained in the hot mix and still in the range of values usually obtained in hot mixes. So a reduction down to 130 ºC is allowed using the Low Temperature Binder.

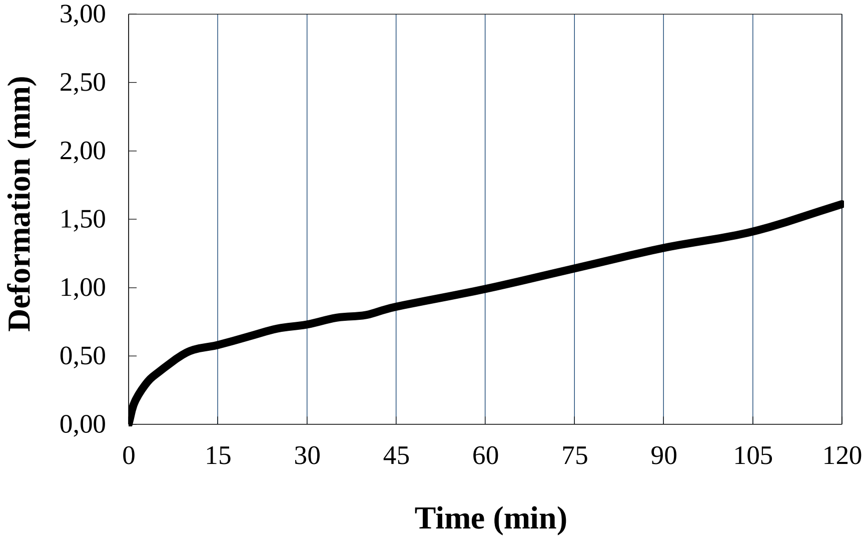
Table 5 : Marshall Test Results

Marshall	Binder T (ºC)	Agg. T (ºC)	Comp. T (ºC)	Density (g/cm^3)	Stability (kN)	Mix voids (%)
B 50/70	155	155	149	2.352 (100 %)	14.4 (100%)	6.1 (100 %)
B 50/70	155	130	131	2.316 (98.5 %)	9.6 (66.7 %)	9.4 (154,2 %)
B 50/70 BT	155	130	128	2.335 (99.2 %)	12.8 (91.4 %)	6.3 (103,3 %)

Resistance to rutting of the mix has been tested by the wheel tracking test as described in the Spanish standard NLT-173 on a mix compacted at 130 ºC. Results, presented in Table 6 and Graph 8, are similar to those obtained regularly for hot mix asphalts, with a final deformation of 1,61 mm and a deformation speed in the last 15 minutes (V105/120) of 13,3 µm/min and complies with the specified values (V105/120 < 15 µm/min).

Table 6 and Graph 9 : Wheel tracking test results.

Time (min)	Def. (mm)
0	0,00
1	0,16
3	0,30
5	0,38
10	0,53
15	0,58
20	0,64
25	0,70
30	0,73
35	0,78
40	0,80
45	0,86
60	0,99
75	1,14
90	1,29
105	1,41
120	1,61
V 105/120	13,3 µm/min



Taking these results into account we can conclude that a WMA manufactured with an aggregate temperature of 130 ºC and a binder temperature of 155 ºC has properties, slightly worst but similar to those of HMA and the values complies with those specified for a HMA. Consequently, these warm mixes formulations are validated in the laboratory and can be thus applied in the field

3.3. Mix production and pavement laying

The Spanish trial took place in the local road CL-612 (Medina de Río Seco – Villafrechós) close to the city of Valladolid, in Castilla-León between August 24th and August 25th. Around 1000 tons of WMA were applied on a surface layer with 4 cm of thickness. The WMA was manufactured using the same aggregates, grading and binder content that the regular HMA laid in the rest of the road.
The works begun on the afternoon of August 24th when seven trucks of WMA were manufactured at 135 ºC and laid at 130 ºC as preparation for the production of the day after.

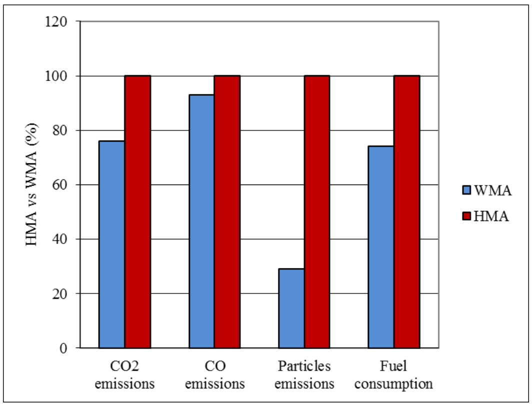
Picture 2: Manufacture and laying of the WMA.

The main trial was done the 25th, producing WMA for the whole day, starting at 7:00 am. The mix was produced on a Intrame mix plant with a production rate of 155 t/h, the same used commonly for the production of HMA. The binder temperature was set around 160 ºC and the aggregates temperature started as 135 ºC and was reduced, due to the good performance to 125 ºC at the end of the works. In both cases the mix looked homogeneous with no uncoated aggregates. No problem of clogging in the dust filter was observed and an important reduction in fuel consumption and fumes produced was recorded by the customer.

Gas emissions were measured at the exhaust of the dryer during the working hours while manufacturing both WMA and HMA and main results are presented in Table 7 and Graph 10. An important reduction of CO_2 (24 %), CO (7 %) and particles (71 %) emissions was noticed, between the fumes produced manufacturing WMA and the fumes produced manufacturing HMA. This reduction is related to a 26 % of savings recorded in the fuel consumption when manufacturing WMA at 130 ºC.

Table 7 and Graph 10 : Gas emission and fuel consumption.

	Savings
CO_2 emissions	24 %
CO emissions	7 %
Particles emissions	71 %
Fuel consumption	26 %



The weather was sunny with almost no wind and temperatures between 20 ºC and 36 ºC. Mixes were manufactured 66 km far away from the works, more or less one hour of transport, and the laying was done at a temperature approximately 5 ºC lower than the mixing one.

A tack coat emulsion was spread on the base course before applying the wearing course. The thickness of the layer was 4 cm and the WMA behaved normally during the whole process of laying and compaction. No adaptation of the paver finisher was required during the laying. Same procedure of compaction than for regular hot mix asphalt was applied (roller + tire compactor) with no difference observed by the workers and achieving same levels of compaction than with the regular HMA used the days before.

Some Marshall Tests were carried out reheating the mix at the production temperature and compacting with 75 blows. The results obtained (Table 8) show good values in all cases, including the mix produced and compacted at 125 ºC, with quite similar density values and stabilities within the 90 % of the HMA ones.

Table 8 : Marshall Test Results

Marshall	Agg. T (ºC)	Comp. T (ºC)	Density (g/cm^3)	Stability (KN)	Mix voids (%)
B 50/70	150	150	2.340 (100%)	13.9 (100%)	4.72 (100%)
B 50/70 BT	135	135	2.337 (99.8 %)	12.7 (91,4 %)	4.81 (101,9 %)
B 50/70 BT	125	125	2,. 45 (100.2 %)	12.9 (92,8 %)	4.36 (92,4 %)

The modulus of the produced WMA was also studied at 20 ºC and 10 Hz using the cylindrical geometry as described in the Spanish standard (NLT-349), again the specimens were produced by reheating and compacting the mixes at production temperatures. There are no big differences between the results (Table 9 and Graph 12) of the HMA produced at 165 ºC and compacted at the laboratory at 160ºC and those of the WMA produced at 135ºC and compacted at 120 ºC, with a higher modulus, or even the one produced at 125 ºC and compacted at 112 ºC with a modulus lower but still on line of those of the HMA.

Table 9 : Modulus Results

Modulus	Mix T (ºC)	Comp T (ºC)	Density (g/cm^3)	Phase angle (º)	Modulus (MPa)
B 50/70 conv	165	160	2.266	15,8	7027
B 50/70 BT	135	120	2.269	17	7713
B 50/70 BT	125	112	2.271	19	6359

4. CONCLUSIONS

The warm mix asphalt (WMA) technology using a "ready to use" formulation of bitumen was evaluated at the industrial scale, by two experimental trials, in Spain and in France.
Minor difficulties appeared in relation to the use of WMA. These difficulties have already been mentioned during a previous trial [4]. 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 or RAP.
Besides, clear advantages of the technology were confirmed by the experiment like the fact that no major adjustment of the production and paving equipments was required.
The gain of the energy consumption, during mixture manufacture, was established by difference in consumptions between 20% and 26% with a significant reduction of the Green House Gas emissions associated.
The technology was tested under different conditions of ambient temperatures, cold and hot, and was implemented successfully, seeing no significant differences between the final results obtained for the WMA and the HMA.
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.
WMA technology matches with different mixes formulations and the addition of reclaimed asphalt pavements. There was a gain of time during the application. Indeed, the use of the low temperature technology for a base course layer allows applying the wearing course layer at the top, quicker than with hot mixes.

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