Environmental and field performance of the warm asphalt mixes technology with a "ready to use" bitumen

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Abstract

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 (WHO, 1999), 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 allow to reduce the energy consumption until 35\% and to reduce CO2 emissions until 40\% (FHWA-PL-08-007, 2008) (Hurley and Prowell, 2006). 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 (Convention d’engagement volontaire, 2009).

Keywords: test trials; warm mixes; “ready to use” bitumen

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1. Introduction

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. 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 hot mix asphalt (HMA), without modification on their plants and on their equipments of application. This paper presents the TOTAL experience of the implementation of the WMA technology throughout two experimental trials, in Blois in September 2009 and in Rennes in April 2010. The trial in Blois was the opportunity to compare the gas emissions reduction and the mechanical performances of HMA and WMA technologies to make wearing courses. In Rennes, we applied both wearing and base courses and we had the opportunity to assess the influence of the addition of reclaimed asphalt pavements (RAP) in the WMA. This paper states the laboratory study carried out before the implementation of the WMA on the field, the complete monitoring of the mixes manufacturing and laying, including emissions measurements and mixes performances, and the follow-up of the trial in Blois.

2. Experimental

2.1. Materials

Conventional Azalt® 35/50 bitumen obtained from TOTAL refineries were used for the HMA industrial manufacturing in Blois and for the laboratory study, prior the test in Rennes. "Ready-to-use" bitumens, Azalt ECO2, were used for the manufacturing of the WMA in Blois and in Rennes. The penetration at 25°C and the softening point of the different binders are listed in Table 1. Both binders comply with European Standard NF EN 12591.

|                  | BLOIS         | RENNES        |
|------------------|---------------|---------------|
| **Penetration at 25°C (1/10 mm)** | NF EN 1426 | 41            | NF EN 1426 | 38 |
|                  | Azalt® 35/50  | Azalt ECO²    | Azalt® 35/50 | Azalt ECO² |
| **Softening point (°C)** | NF EN 1427 | 52.6          | NF EN 1427 | 52.9 |

In Blois, the applied mixes are EB 10 (BBSG 2 0/10) as defined in the European Standard NF EN 13108-1. In Rennes, 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.

2.2 Environmental measurements

Environmental measurements were realized only during the Blois trial, to compare HMA and WMA.

- 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.

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, gas and electricity consumption were measured along with airborne emissions, volume fractions of O₂, CO₂, NOₓ, CO, Non-Methanic Gaseous Organic Compounds (NMGOC) and CH₄ 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 1.

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 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 2. This method has already been fully described (Jullien et al, 2006).

![Figure 1: Principles of gas sampling and analysis at the main stack](image1)

![Figure 2: Confined test principle using the flux chamber (assessment of GOC emission potential during lay down stage)](image2)
As for transport the data are provided by Hugrel et Joumard, 2006, while for roadworks engines, they are obtained from FD P 01-015 standard, 2006.

- 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 (Sayagh et al, 2010). 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 Jullien et al, 2005, while data on equipment engines were extrapolated from previous measurements (Jullien et al, 2005). Airborne emissions were then calculated from consumption values in accordance with a methodology previously published (Paranhos, 2005).

  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 selected environmental system is depicted in Table 2 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.

| 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           | Lack of available validated data, not considered               |
| Additive 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                            |

Table 2. System boundaries.

Classical environmental indicators were calculated from environmental emissions, according to equation (1):

\[
I = \sum_i \alpha_i C_i m_i
\]

\( I \) indicator of the examined impact category (e.g. greenhouse effect),
\( \alpha_i \) Classification coefficient (unitless) representing the percentage of compound \( i \) involved in the considered impact category,
\( C_i \) Characterisation coefficient of 1 kg of compound \( i \) to the impact category,
\( m_i \) Mass of compound \( i \) (kg).

The methodology implemented to calculate mass flows depends on analyzer type, as explained by Paranhos et al, 2005. The coefficients are given in Table 3.
3. Results and discussion

3.1. Test trial in Blois

- Mixes production at the industrial scale
  The road trial has taken place over three days from September 29th to October 1st 2009.
  The HMA were manufactured 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. 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 Azalt ECO2 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 bitumen Azalt ECO2 was unnoticeable.

- 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 characteristics of the mixes are listed in Table 4. 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 indicating a slightly higher susceptibility to moisture, 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 4. Characteristics of the HMA and WMA produced in the plant. Measurements realized by the LRPC of Blois.
Pavement laying and compaction

The road RD957 is a four lanes road with a high traffic level (traffic T1).

The mix from the first truck of WMA 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 mix was laid and compacted between 115 and 105°C. The thickness of the mix was 6 cm. The mix behaved normally during the whole process, we observed no problem during the laying and the compaction. 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. Moreover, the working temperature reduction suppresses the smell at the mixing plant and on the job site too.

The HMA 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.

Environmental measurements

The resources consumption is reminded in Table 5 at the bottom for the sake of comparisons. To better show the difference between the two studied asphalt, Figure 3 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 5. LCI for considered pollutants, the plant-road work distance is of 10 km.

| FLUX             | UNIT | Plant   | Road works | Transports (10 km) |
|------------------|------|---------|------------|--------------------|
|                  |      | 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 |          |          |            |                   |                    |
|                  |          |          |            |                   |                    |
| CO₂              | MJ/UF    | 4 215    | 2 621      | 506               | 579                |
| CO               |          | 92,35    | 10,38      | 1,40              | 1,61               |
| NMCOG            |          | 5,35     | 6,20       | 0,35              | 0,41               |
| NOₓ              |          | 2,43     | 0,87       | 6,45              | 7,38               |
| CH₄              |          | 0,13     | 12,70      | ***               | ***                |
| SO₂              |          | 5,10     | 2,76       | ***               | ***                |
| dust             |          | ***      | ***        | 0,35              | 0,41               |
| N₂O              |          | ***      | ***        | 0,07              | 0,08               |

| 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      | ***               | ***                |

- 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. They are very satisfactory and are equivalent for the HMA and WMA, on the driving and the passing lanes.

Figure 4. (a) Measurements of the transverse deformations and the rutting on the slow lane, before the works and after 1 year of service. (b) Macrotexture measurements using a Rugolaser 2.

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 4a). 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 4b). 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 Azalt ECO2 does not damage the mechanical performances of the road.

3.2. Test trial in Rennes

After the first field trial of the Azalt ECO2 bitumen in Blois in September 2009, 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 confirm the ability of the Azalt ECO2 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.

- Laboratory study

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 the trial in Blois showed that the rutting and the Duriez tests results were similar for HMA and WMA. For this reason, we focused on fatigue and modulus measurements, realized for the base course mix EB 14.

The WMA were made with aggregates at 120°C and the Azalt ECO2 bitumen at 165°C for the laboratory tests. The characteristics of fatigue and modulus, measured for the mix EB 14 are displayed on the Figures 5a and 5b.

Figure 5. (a) Compression modulus for the hot and warm EB 14NF EN 12697-26, (b) Fatigue test for the hot and warm EB 14 NF EN 12697-24A1

The modulus measurements were realized 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 it respects the specification of the European standard (Figure 5a). The fatigue resistance is measured using the two points flexion method on trapezoidal samples (Figure 5b). As for the modulus, the value measured for the WMA is slightly lower than that of the HMA but it respects the specifications defined in the European standard NF EN
Regarding the precision of these measurements, the differences of the fatigue and modulus values between HMA and WMA are not significant. In conclusion, these warm mixes formulations are validated in the laboratory and can be thus applied to the field.

- Mix production and pavement laying

The WMA were made at 120°C with aggregates at 120°C and the "ready-to-use" bitumen Azalt ECO2 at 145°C. The total quantity of mixes was approximately 470 tons. The production flow of plant was set to 110-120 t/h and the power of the burner was adjusted to 56-60% of the maximal power. Then, the temperature was maintained at 125°C, with no problem at the level of the plant. The customer was very satisfied with the coating quality of the aggregates because they are generally difficult to be coated, even the manufacturing of 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% of the plant consumption of fuel oil at the level of the plant with regard to the production of hot mix asphalts.

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. No adaptation of the paver finisher was required during the laying. Nevertheless, the WMA were generally more difficult to handle manually for the workers.

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 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. As the day before, the smell of the bitumen was not noticeable and we observed no clogging of the dust filter even if the temperature of the fumes remained quite cold.

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 compacties were measured directly on the pavement using a gamma densimeter (Figure 6). The values are satisfactory for all the mixes and slightly higher for the WMA containing RAP materials.
4. Conclusion

The warm mix asphalt (WMA) technology using the "ready to use" bitumen, Azalt ECO2, was validated at the industrial scale, by two experimental trials, in Blois and in Rennes.

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. Under cold conditions, some sticking on the finisher and compactor wheels can occur.

Besides, clear advantages of the technology were confirmed by the experiments. The delivery of a “ready to use” binder was very much appreciated by the users, along with the fact that no major adjustment of the production and paving equipments was required. 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. WMA technology matches with different mixes formulations and the addition of reclaimed asphalt pavements. 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. The use of the low-temperature technology suppresses the smell at the mixing plant and the job site.

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, including Energy Consumption, Global Warming Potential, eutrophication, acidification, Photochemical Ozone Creation.

NOTE

The research sponsoring organization and the authors do not endorse any proprietary products or technologies mentioned in this paper.

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