WILL BITUMINOUS MIXES BE MADE DIFFERENTLY TOMORROW: STATE OF THE ART FOR WARM-MIX ASPHALT IN FRANCE

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ABSTRACT

Industrialized countries concentrate their road policies on improving safety conditions and on easing road displacements, and they also focus on protection with respect to the bordering populations, maintenance workers and, in a more general way, the environment.
This paper provides an assessment of the current research on hot bituminous mixes, produced by various means, from the perspective of meeting environmental requirements, and reducing power consumption. After defining the terminology describing bituminous mixes, the general principles of the various processes of making warm mixes of asphalt are presented. The range of these bituminous mixes includes the techniques known as semi-warm (temperature lower than 100 °C) and techniques known as warm (temperature higher than 100 °C, with a reduction of 20 to 40 °C compared to traditional hot bituminous mixes). The characteristics and performances expected from these bituminous mixes, both mechanical and environmental, are reviewed. The results provided by companies and from some follow-ups carried out by the Scientific and Technical Network (RST) provide comparative studies from the laboratory and the early phases of on-site performance.

1. INTRODUCTION

The industrialized countries' road policies concentrate on improving safety and on the comfort of road displacements, and also focus on protection with respect to the bordering populations, the workers and, in a more general way, the environment. This improvement includes a judicious choice of structures (durability), and especially in the nature of wearing courses, which makes it possible to offer a combination of better conditions for skidding resistance while providing a significant decrease in pavement tire noise and a better division of the space placed at the disposal of the various road users.

The planet has been getting warmer – global warming has long ceased to be a subject of scientific debate. In France, the storm in 1999 and the heat wave in the summer 2003 are the harbingers of the dramatic changes to come. With an average temperature of 14.6 °C, 2006 was the warmest ever recorded. Over the last 10 years, climatic catastrophes have caused 0.9 million deaths, significantly disrupted 2.6 billion people, and caused financial losses exceeding 210 billion dollars. Climatology scientists predict a decrease in the ice-barrier surface of 40%, causing a rise in the sea level, that would result in 1.2 billion people affected and create 200 million climatic refugees by 2050. There is urgency and we must act and reduce our emissions significantly, initially to stabilise them by 2010, then to divide them by four, by 2050 [1].

Against this energy challenge, Plan Climate 2004 [2] answers the objective of Kyoto, and even goes beyond: in total, these measures represent a savings of 72 million tons of CO_2, the principal greenhouse gas (instead of the 54 million predicted by Kyoto) each year, beginning in 2010. More recently, the European meeting of Brussels, in March 2007, laid down the objective of reducing CO_2 emissions to a total value of 20%, compared to 2002, within ten years.
The environmental stakes are very high, compounding the climatic challenge and the increase in demand for raw materials and energy. Since the beginning of this century, environmental issues, especially global warming, have been at the centre of the axes of work in the research and development centers of the major oil and road surface companies. The development of a range of warm mix asphalt (WMA) technologies represents an important stage of this program and could be an operational concretization along the path of sustainable development and effective environmental protection [3], [4], [5]. This article will describe the various processes and provide an assessment of the current research regarding WMA.

2. WHY WARM-MIX ASPHALT (WMA): A STYLE OR A NECCESSITY?

Proponents of WMA aim to:

- reduce the harmful effects (fumes, odours, gas, vapours) at manufacture as well as at implementation, particularly important in poorly ventilated spaces (tunnels, multi-level and/or interior parking lots , narrow downtown areas, etc.).
- limit the production of greenhouse gases (GHG),
- reduce power consumption during the partial drying of the aggregates, and
- allow major road companies to play their part in the general policies of countries that are signatories to the Kyoto protocol. These companies have developed technical innovations resulting in producing a more “ecological” bituminous mix, now operational, that can contribute to environmental protection.

The general principle of WMA is to lower the mixing temperature while preserving the workability of the mixture for layout and compaction. It is a question of finding a manufacturing process, compatible with the current mixing plants, which artificially maintains the viscosity of the binder throughout the period of application. This period can be extended to approximately 2 hours, while allowing an effective compaction (porosity in conformity with specifications) and good placement of the bituminous mix (texture, roughness, homogeneity, etc.).

WMA is not a momentary ’fad’, but a solid response to the reality of today with a view to the future. This process provides a high-quality bituminous mix, adapted to the constraints of modern roadways, while privileging respect for the environment and reducing the high energy costs associated with hot bituminous mixes.

3. TERMINOLOGY – DEFINITION - ATTEMPT AT CLASSIFICATION

WMAs are composed of a family of bituminous mixes prepared at hot temperatures, but whose exit temperatures at manufacture (at the level of the mixer) vary from 80°C to 130°C, depending on various mixture processes. These products respect the standards or specifications corresponding to the class of bituminous products to which they refer (for example the grained semi bituminous mix: NF P 98-130).

The temperature of manufacture (left central) and spreading constitutes one of the means of classifying bituminous products as:

- cold mixtures (temperature < 60°C), comprising mainly bitumen binders with emulsion or foamed bitumen,
- warm or semi-warm asphalt mixes (between 60°C and 130°C), defined according to whether the exit temperature at the mixing plant is:
  - under 100°C,classified as semi-warm asphalt mixes
  - above 100°C, known as warm-mix asphalt.
- Traditional hot bituminous mixes (> 130°C).

For simplification purposes, in this paper, the term warm-mix asphalt (WMA) will indicate both the warm and semi-warm mixes.

We must keep in mind that traditional hot coating facilitates, due the temperature effect, interfacial conditions that ensure an effective and durable adhesion between the bitumen and the aggregates. With this intention, the aggregates are dehydrated and heated to more than 170 °C. The bitumen must have a coating viscosity lower than 150 cSt; which means a temperature ranging between 120 to 180 °C according to its grade (10/20 to 70/100 for France). The temperature of manufacture of hot bituminous mixes is thus between 130 and 180 °C.

WMA coating techniques include the three following features or conditions:

- no major addititives (other than foaming or adhesion agents) where the process consists of control of the water content in the form of vapour in the final mixture,
- sequential or multiple coating, with or without the use of foamed bitumen,
- the addition of additives to modify the viscosity of the bitumen (special binder, adding water or maintaining free water, paraffin or a similar material).

Certain processes involve two of these aspects (for example: foamed bitumen and hygroscopic filler).

The initial schedule of conditions of the warm-mix asphalt, which gained some consensus within the road community, treated coating differently than the hot processes while maintaining:

- a complete and uniform coating,
- a binder without fluxing or expectorant agents of fossil origin,
- nominal mechanical properties at the end of implementation,

by lowering the temperature of manufacture and compaction, using a process that can control the viscosity of the binder until the implementation is complete.

WMAs are in conformity with the French standards (and soon the European, with French application to the 1/1/2008) for hot bituminous mixes [6], [7] and must respect the properties in the laboratory (mechanical and state characteristics) and on job sites (texture, voids content, thickness). The mix design in the laboratory follows the same process: similar levels, the same tests and the same specifications as the hot bituminous mixes. On job sites, the only difference relates to respecting the temperature conditions, which must be specified in the companies' chart of the process. Standards specific to warm bituminous mixes is not envisaged in France and in Europe. WMAs are also under development in other European countries.

4. DESCRIPTION OF THE PRINCIPAL TECHNIQUES

The principle of the warm bituminous mix is to be able to find a means of disseminating the bitumen in the mineral skeleton and of preserving good handiness and compactability by:

- the effect of plasticising the bitumen by additives, stable at roadway service temperatures ,
- the effect of “soup” or “foaming”, creating water-in-oil emulsion by good control of the water at the coating phase , and preserving this effect at placement,
- the double coating effect (for example: traditional soft bitumen coating and hard bitumen injected in foam) or sequential coating,
- the effects of the specific properties of binders, for example: synthesis binders of vegetable origin,

An alternative to semi-warm mix asphalt is to reheat cold asphalt mix treated with the bitumen emulsion (process: Ecomac). This process of “cold bituminous mix warming” improves the handiness and thus increases the mechanical properties and surface resistances to wrenching. This process allows a better control of the implementation and homogeneity of the coating. For the remainder of this article we will limit ourselves primarily to WMA.

Table 1 - Designations and principles of WMAs used in France

Technique	Name	Company	Principle of manufacture
Addition in bitumen	SASOBIT	Germany	Hot skeleton + bitumen + paraffins or waxes (low molecular weight)
Addition in mixer	ASPHA-MIN	EUROVIA	Hot skeleton + zeolites + bitumen
Special bitumen	3E – LT ECOFLEX	COLAS Group SCREG	Hot skeleton + special bitumen (ready to use)
Special binder	VEGECOL	COLAS Group	Hot skeleton + synthesis binder of origin plant
Double coating	WAM FOAM	SHELL Netherlands Italy	Hot skeleton + soft bitumen + hard bitumen in foam
Double coating	3E - DM	COLAS Group	Hot skeleton + soft bitumen + foamed bitumen
Double coating	LT asphalt	NYNAS – (Netherlands)	Hot skeleton + hygroscopic filler + foamed bitumen
Sequential coating	3E - DB	COLAS Group	Hot skeleton + soft bitumen + hard bitumen
Sequential coating	EBB (LEA) – mixes low energy	FAIRCO	Hot fine gravels + bitumen + wet sand
Sequential coating	EBT (LEA) – mixes low temperature	EIFFAGE TP	Partially heated skeleton (95°C)+ bitumen or Hot fine gravels + bitumen + wet sand
Cold warmed bituminous mix	ECOMAC	SCREG	Cold skeleton + emulsion + reheating

The processes of WMAs (or semi-warm) developed and used in France are summarized in table 1, according to a classification depending on the manufacture process. The commercial name of the product and the road or oil company that developed it are presented. The original techniques and processes have been patented by these companies.

Ecomac: drum “warming”, application in wearing course on a road with medium-heavy traffic. Note the absence of emissions (photo credit: Y. Brosseaud LCPC).

The principles of coating are described briefly in this section. For more details, the reader can refer to the companies’ communications (see references).

The Sasobit process consists of “softening” the binder by wax fusion at 100°C and solubilisation with the bitumen (115°C). The bitumen thus “plasticised” is prepared by an in-line mixer (4 to 5% of Sasobit). This ready-to-employ binder can be used in any type of power station, without modification. It allows the manufacture of the bituminous mix at an average temperature close to 130°C (temperatures are lower by 30 to 40°C compared to the traditional hot bituminous mix). It allows an effective compaction until 80°C. This bituminous mix presents a good behaviour at low temperatures and a better resistance to rutting. This technique is especially employed in Germany. In June 2005, a laboratory evaluation of this technique was performed by the National Centre of Asphalt Technology (NCAT) [8].

The Low Temperature Asphalt process (LT Asphalt) [9] is based on coating the mineral skeleton with foamed bitumen, carried out at 90°C. A hygroscopic filler (0.5 to 1% of the mixture) retains the free water contained in the non-dehydrated mineral fractions, and makes it possible to maintain good compactability. This technique is still under development in research laboratories in the Netherlands. There have been a few applications to date.

Warm mix asphalt containing Zeolite: mixes with aspha-min were developed more than 4 years ago [10]. The Zeolite used is aspha-min, made up of crystals of hydrated aluminosilicate, which is in the form of a powder. In the presence of aggregates at 130°C, Zeolite (at close to 0.3% of the mixture) releases its crystallised water (crystallised water concentration approximately 20%), producing vapours and expansion in the form of hot foamed bitumen, promoting coating and handiness. This additive reduces the temperature of manufacture of the bituminous mix by about 30°C. A laboratory evaluation of this technique was carried out by the National Centre of Asphalt Technology (NCAT) [11].

Application of warm-mix asphalt to aspha-min ESG-10 PG 70-28, Bali Street in Montreal (Canada), August 2005 (photo credit: Y. Paquin DJL - EUROVIA)

The Low Temperature coating process - EBT (Low Energy Asphalt **- LEA** for export) is manufactured according to two specific drying procedures:

- all the aggregates are heated at 95°C (procedure α), or
- a part of the aggregates is dehydrated and heated at 130°C and the other part is heated at ambient temperature and controlled moisture, and is re-introduced by a specific means (ring for recycling, carpet launcher, in the mixer) (process β).

In the mixer, water is added to have total water content close to 1.5%, then the hot bitumen is injected. The free water makes the bitumen foam naturally, creating spontaneous auto-expansion of the bitumen, and promoting aggregate coating. The warm-mix asphalt is thus prepared at a temperature of 90°C. An additive improving the workability and the quality of adhesion is sometimes added with specific aggregates. This process requires only minor adaptations to the mixing plant: assembly of the means to add water to the mixer, equipped with a metering pump. Currently about fifteen plants are equipped with this device. The compaction requires a mechanical energy slightly higher than for the hot traditional mixes of asphalt. The temperature of compaction is between 70 and 90°C [12], [13].

EBT: application of 4500 tons of warm mix asphalt BBA 0/10, aerodrome of Candillargues (photo credit: EIFFAGE company Public Works)

The bituminous mix process with Low Energy – EBE (still indicated as Low Energy Asphalt - **LEA** for export), is the first process developed for semi-warm mixed asphalt (under 100°C). The innovation involves the introduction of wet sand after the dry gravels have been coated by bitumen [13], [14]. The success of this process lies in the control of the final water content in the semi-warm mix asphalt, which preserves its workability for compaction for a sufficient duration. The principle appears to be very simple, but it took a significant amount of work on the mode of introduction of the wet sand, and consequently to develop specific modifications at the coating plant [12]. The EBE process privileges the thermodynamic approach, without forsaking the physicochemical aspect [13]. The fine gravels are dehydrated and heated at 130°C and mixed with the hot bitumen, then sand is introduced at ambient temperature, its moisture being adjusted so that the final mixture has a water content close to 0,5%. Thus, the process successively mobilises the properties of the bitumen depending on its various states: hot and thus at low viscosity for coating the dehydrated fine gravels; in expanded form (or foam) and emulsion when this hot bitumen, above that needed for the fine gravels, is put in contact with the interstitial water in the sand. An additive (0,3 to 0,4% of the weight of the bitumen) is added during manufacture to support adhesion (with some not very adhesive aggregates) and for the "foamability" of the binder. This technique thus allows manufacture of the bituminous mix at a temperature close to 90°C and its application between 60 and 90°C.

Thermal calculations of losses, validated by experiments, showed that the speed of cooling of the bituminous mix at low temperature was much lower compared to the traditional hot bituminous mix (130-140°C) and thus the period of implementation (and consequently of compaction) was lengthened [15].

Mixing in laboratory: very little emission of dust, bulk material before Gyratory Shear Compaction (PCG) test, absence of fumes, some light vapours.

(photo credit: D. Sicard LROP)

The bituminous mix process 3 E – **Environmental Treasurers in Energy (3 E)** - are the fruit of this companies' research and experiments with WMAs [16], [17]. The schedule of conditions associated with this research program worked towards product performance comparable with the traditional bituminous mix, able to decrease 40°C from the temperatures of manufacture and implementation, while using all of the types of coating plants, without amendments or with minimal adaptations. The research program led to 3 products, whose common characteristics are in conformity with the schedule of conditions, and which can be implemented at between 80 and 110°C.

3E "DB" Process: involves double coating of the bitumen, carried out sequentially by two types of bitumen of different penetrability, to adjust the viscosity of the final binder. The aggregates are dehydrated and heated close to 125°C, then coated initially with the soft bitumen, then with the hard bitumen. The final penetration of the binder is selected according to the intended use.
3E "DM" Process: coating is carried out sequentially. The dehydrated aggregates are heated close to 125°C, coated with a hot bitumen, and then undergo the second mixing with foamed bitumen, whose grade is adapted to the desired end product.
3E "LT" Process: coating is carried out in the traditional way, except for the heating temperature, always maintained around 125°C. The "LT" binder, modified by additives, is specifically engineered in this groups' factories. It is pulverised on the aggregates.

The Wam Foam process comes from research development undertaken by an oil company [15]. This process' coating principle rests on three successive stages, involving a soft and a hard bitumen. The aggregates are dehydrated and heated to 110 - 120°C, then pre-coated by soft bitumen (generally of penetrability 300), promoting a very good wetting and adhesion of the various mineral fractions. The second coating, by foamed hard grade bitumen, completes manufacture. Mixing of the hard foamed bitumen and the aggregates pre-coated with soft bitumen supports the process of recombination of the bitumens (application of the mixture theory). Installation at the plant is not complex. The manufacture of foam requires a good extraction of air. A device for cleaning the tubes in the mixer uses a system of compressed air.

5. DEVELOPMENT OF THE PRODUCTS

5.1 Achievements

It is always very difficult to obtain sufficiently precise figures to evaluate the evolution of processes. However, the orders of magnitude provided by the companies make it possible to locate them in a general context and consequently to assess their degree of development.
The studies and research began in the laboratories over a period ranging from 2000 to 2003. The first experiments were carried out between 2002 and 2005, depending on the progress of the various studies.
To date, the achievements have already been numerous in terms of job sites and sometimes in tonnage, as indicated by the data communicated by the road companies. These include:

- Warm mix asphalt with aspha-min: more than 120 references in August 2006, that is to say nearly 180.000 tons applied since 2004, including nearly 100 000 tons applied in 2006 alone, and in various countries: 75% in France, the remainder in Germany, Croatia, Canada, and the USA.
- EBE: the modifications made at a mixing plant in the Paris area have been operational since the middle of 2005. Experiments were carried out in 2006 in the USA.
- EBT: the technique has been regarded as operational since 2005. More than fifteen plants are equipped to produce this bituminous mix, which was deployed in ten realisations in 2005, using 2 to 3 000 tons.

The latest assessment, drawn up at the end of 2006 on EBB and EBT techniques, gives a report on the realisation of 70 building sites and nearly 40 000 tons of WMA.

- 3E and ECOFLEX: an assessment of ten building sites was made in 2005, where approximately 5.000 tons of bituminous mix 3 "E" was implemented, using various techniques. Also, implementation was successful on a significant number of sites in 2006, mainly according to technique LT.

- **Sasobit:** no application has been listed in France, but it has been applied in the Netherlands and in Germany (no data was collected within the framework of this assessment).

- Wam Foam: some road experiments were carried out in Italy, including a significant application on the binder course on 3.5 km of motorway in 2006 (no data was collected for this assessment).

These figures show the advanced degree of development of WMA techniques.

5.2 Bituminous mix typology manufactured according to WMA processes

The traditional bituminous mixes, like the thick semi-coarse bituminous mix (BBSG), applied in surfacing courses (binder and wearing courses), and manufactured according to a continuous grading curve with traditional pure bitumen (grade 35/50), have tested successfully, according to various processes indicated above (for applications in France).

The use of a traditional structuring bituminous mix, like "grave bitumen" (gravel treated with bitumen), does not raise a particular difficulty for its' manufacture and implementation at the roadway site. However, according to the principle of precaution, and in anticipation of long term mechanical evaluations, certain companies are more cautious, and do not currently plan to employ WMAs. Others propose these warm techniques for structures supporting significant heavy traffic.

The use of hard bitumen (10/20 or 20/30) for the manufacture of bituminous mix with high module (EME) in roadway reinforcement was tested successfully with the EBB, EBT and aspha-min techniques.

Similarly, successful tests of bituminous mix with binders modified by polymers were also conducted with certain warm processes. The performances obtained have been reported as being comparable with those of the same bituminous mix to the polymeric binders using the traditional hot method (considering that the viscosity of these binders is higher when the mixing temperature is slightly higher).

A question arises: will it be possible to produce the whole range of the hot bituminous mix(es) according to these warm processes?

According to certain information from the road profession, it would seem that all the types of bituminous mixes, even for base courses or surfacing courses, can be prepared according to modes of WMA production. However, this assertion remains to be confirmed by experiments, in particular with regard to the very thin bituminous mix (BBTM) of 2 cm, and the porous asphalt mixes. Till now, these two processes have not been realisable according to the technique of the cold bituminous mix with the emulsion bitumen.

But is it necessary to systematically seek a complete substitution of hot bituminous mix by warm bituminous mix?

The question must be examined, and the answer must be reasonable. The estimates for the reduction of $C0_2$, the principal greenhouse gas, would be close to 400.000 tons for the entire

French production of hot bituminous mix (approximately 45 million tons). An even partial recourse to these warm processes would have a significant beneficial effect on the reduction of greenhouse gases and in the field of roadwork. This situation could be a worthy example, offering encouragement to the other branches of public works to develop more "eco-durable" techniques sought after by today's development policies.

5.3 Promotion of WMA Innovations

With the aim of encouraging companies to innovate, charters of innovations have been signed and they show the establishment of certificates and rewards that are allotted at the time of competition based on innovation in the field of public works.

A charter motorway innovation obtained a certificate, issued in 2006, attesting that "the *process tested (warm mix asphalt with the aspha-min) on a thick bituminous mix (BBSG 0/14) and a thin bituminous mix (BBM 0/14), led to a drop in the temperature of drying of the aggregates of 30°C in the mixer during coating by the bitumen. The assessment proves to be convincing with respect to the objective of reduction of the mixing temperature while preserving the characteristics of the hot bituminous mix. It makes it possible to notably decrease the power consumption and the harmful effects associated with the emission of fumes and dust in the atmosphere. It contributes to reducing GHG appreciably*".

In a similar fashion, competitions based on the promotion of this innovation [18], organised by the public works professions and building owners, proceeded based on warm bituminous mix techniques, like:

- warm mix asphalt containing aspha-min,
- bituminous mix low energy: process "EBE".

These recognitions attest to the unquestionable development and satisfactory behaviour, at least in the short term, of WMA techniques.

6. FIRST ASSESSMENTS

Generally, the results presented in this synthesis come mainly from data communicated by companies. The few achievements followed by the RST lead to the same conclusions. A more important and bearing sampling on the whole of the techniques proves to be necessary to have an opinion to give full details. A larger sampling, including heavy traffic areas and comparing the whole range of these techniques will be necessary in order to provide fuller details.

6.1 Environmental assessment: temperatures of manufacture, emissions

The energy gains due to the reduction in fuel consumption for the drying of materials are about 1 to 1.5 litres per tons for the warm processes, and of almost 1.5 to 3 litres per ton for the semi-warm processes. In this case, the economy relates to the energy not consumed for the vaporization of water. The latent heat for the of vaporization of water (537 kcal/kg)

represents 500 times more energy than that required to heat by one degree the same quantity of water.
The reduction in fuel consumption is very significant, since it is between 25 and 50%. This would represent a potential of reduction of approximately 0,7 million tons of oil, if all of the bituminous mix made in France were produced according to this new process (there does not seem to be a convenient means to generalise this manufacturing process for all costs, diversity remaining a means of optimising the production and the cost). The official reports carried out on job sites attest that WMA reduces the temperatures of manufacture, in a range of 25- 60°C, according to the nature of the processes. Thus each of these processes, known for their lower energy consumption, contributes to reducing the energy bill and consequently to decrease very appreciably the gas or and solid emissions.

The information communicated by the companies for the first results concerning the gas emissions are from measurements carried out by specialised engineering and design departments in France (INERIS, VERITAS) and abroad (Belgium and Germany). These measurements of rejections in the atmosphere show:

- emissions at the exit of the coating plant chimney are significantly reduced,
- emissions of the volatile organic compounds (COV) are decreasing,
- emissions of GHG like CO_2, NO_2 and SO_2 are reduced in the same proportion as the energy gain, which is about 25% to 50% according to the processes.

Measurements of the effects on the personnel at implementation were also taken. The rates were extremely low, and often at the extreme range of detection for the apparatuses and methods used, and thus it is thus quite difficult to show improvements. However, one can confirm the significant absence (with the protocol used) of emission for the hot or warm bituminous mix. Dust inhalables have been found, according to companies' measurements, at levels much lower than the average values of exposure for personnel (in France: 5 Mg/m3 for 8 hours of exposure; 0.5 kg/m3 recommendation of the intergovernmental conference on hygiene in the USA) [17].

The working conditions of the personnel are clearly improved with WMA: there is no longer, or now very little, steam released at the building site. The temperature of the building site has become acceptable, especially when the summers are very hot. In the event of sudden bad weather, there is no vaporisation produced from the hot-coated material, which had led to visibility problems for the drivers, and the possibility of serious accident for the operators (agents crushed by the compactors because of the thick vapours).

Research is needed to develop equipment and protocols of specific tests, unified to quantify the emissions (nature and rate) emitted by various bituminous techniques, regardless of the principle of manufacture. Measurements of gas and solid emissions, as well as environmental assessments must be performed during the evaluations of the warm processes, to verify the actual gains as regards consumption - including emissions at the power station (toxic compounds: aromatic hydrocarbons Polycyclic HAP, COV, etc.), and for the implementation itself. Analysis of the life cycle, from the production of the components, including those introduced in very small quantity into the mixture, continuing through the production, application, assessment of use and until the end of lifetime of the product, must be carried out to consolidate the data for this warm bituminous mix, compared to the traditional hot, or cold bituminous mix.

6.2 Mechanical properties

The formulations of WMAs are similar to those of the hot bituminous mixes, except for the built-in additives. These are introduced either into the binder (agent foaming, via adhesiveness or surfactant), in the materials (humidification of sand), or in the mixer (hygroscopic additives), with weak proportioning (some 0.3 per thousand to 4% in the bitumen, 1 to 2% for water, addition at a rate of 0.2 to 0.4% of the mixture).

The laboratory performances of WMAs have proved to be very comparable to bituminous mixes prepared according to the conventional manufacturing process. Table 2 presents examples of results communicated by the companies and reports from some achievements followed by the RST. It should be noted that it is advisable to carefully examine the behaviour of WMA with respect to resistance to stripping under wet conditions (with the Duriez test) and to plan, with certain types of aggregate, the use of a special adhesion agent.

Table 2 – Examples of performance comparisons between traditional hot bituminous mixes and WMA (manufacture in laboratory or on job site)

	Without - With aspha-min BBSG (laboratory-job site)	**Without - With aspha-min BBSG** (building site Motorway)	**Heat – Warm EBT BBSG 2 - 0/10** (laboratory)	**Heat – Warm EBE BBSG 2 - 0/10** (laboratory)
Data	RST	Company	Company	RST
Binder	35/50	35/50	35/50	35/50
Temperatures (°C)	155 - 123		160 - 90	150 - 85
% voids (PCG 60g) average (job site) extended (job site)	8.5 * 5 - 7.5 4/5 - 5/9	6.5 - 7.3	9 - 7	7.5 - 11.5
Duriez r/R (%)	0,95 *		0,94 - 0,84	0,9 - 0,95
Rutting (%) after 30.000 cycles	4,6 *		6,4 - 6,5	6.0 - 6.1
E $_{15°C-10Hz}$ (***MPa) E $_{15°C-0,02S}$ (***MPa)		10 400 - 11 300		WM - 8 300
Fatigue resistance Ep 6			105 ** - 104 **	
Sand patch test (mm)		0.98 - 1.03		

WM: without measurement
* comparable results (with and without aspha-min)
** value estimated starting from the void content modification

As far as mechanical behaviours, the measurements carried out on the experimental job sites have led to results generally rather similar to those obtained with the traditional hot bituminous mixes. Thus at the early stages, or after one or two years of follow-up, there does not seem to be significant differences.

There is rather limited data on the mechanical properties (module complexes and resistance in fatigue), which comes from company studies (studies of formulations in the laboratory and taken at job sites). The results show values in conformity with the specifications imposed on the hot bituminous mix.

But what will be the long-term performance, especially for durability (ageing) and fatigue response?

A new Operation of Research “OPTIMIRR” – Optimisation of economical road Materials and Incorporating Recycled Road [20], registered in the research program on “materials and economical structures in nonrenewable resources” of the four-year contract of the LCPC, began in 2006 and has been charged to bring answers to these questions.

Only full-scale tests on structures subjected to heavy loads could give us an answer, which could then be compared to the traditional hot mix asphalt. The fatigue test track in the Nantes LCPC centre will most likely accommodate this type of experimentation, before embarking on very large-scale industrial applications. These tests could make it possible not only to evaluate the long-term performances of WMA, but also, if necessary, to propose new shock coefficients to be introduced into the calculation models of pavement design and to assess new types of behaviour or degradations (the sensitivity particular to ravelling or stripping, for example).

6.3 Surface properties, conditions for placement and return to service

Although applied at lower temperatures, the handiness of the bituminous mix does not seem to be affected, as testified by the results concerning the porosity in place, qualities of roughness (sometimes a delicate characteristic to satisfy with cold bituminous products), surface texture, adherence, or the quality of the gaskets between spreading bands. The measurements carried out on the experimental sites lead to results comparable with those obtained with traditional hot mix asphalt. Thus at the beginning, or after one or two years of follow-up, there does not seem to be significant differences.

As indicated above, we can even estimate that for certain processes the application time can be as much as doubled, compared to the traditional hot bituminous mix. This would allow an increase in the hauls: job site – mixing plant, and extend the period of placement of the bituminous mix to lower temperatures (between 5 to 10°C, for example). This last characteristic was validated in Canada, where there was a successful application of hot bituminous mix produced at less than 100°C (according to a process developed by a Canadian company), at temperatures around 5°C, with good workability and satisfactory compaction.

Using WMA leads to temperatures of the end of compaction that are lower than with the traditional hot mix asphalt (55°C compared to 80°C depending on the process). That constitutes an important advantage because it allows the roadway to be opened to traffic much quicker, without risk of permanent deformations.

6.4 Equipments of manufacture (plant): consequences

Depending on the process, the modification to be made at the coating stations may involve:

- the mode of introduction of the additive according to its nature (pellet, fines or liquid) by the ring of recycling, the circuit of the recovery filler, the fusible thermo bags in the mixer, an online batcher, a ponderal batcher, addition of binder in the tank, or other means,
- the introduction of sand at ambient temperature and adjustment of its moisture (water content sensor, water tank, and sprinkler device), by a specific circuit or the ring of recycling,
- the manufacture of foam,
- double coating (a separate circuit for wet sand) ;

In practice the modifications are rather minor. Road-work companies have already implemented these technologies. These solutions remain mostly relatively low-scale (industrial feasibility has already been demonstrated). Of course, it will be advisable to evaluate the economic impacts on current installations.

In the future, the manufacturers of materials will develop more powerful industrial systems to continue to improve energy efficiency (new burners adapted better to lower operating temperatures), the sequences of manufacture with or without additives (ex. double coating, double binder) and the recovery and evacuation of steams, avoiding any condensation and corrosion. Manufacturers are working on these new mixing plants for the production of bituminous mix with lower energy consumption [21].

7. CONCLUSION

The research efforts of the road and oil companies have led to the adjustment of processes in the operational field, making it possible to produce WMAs.
Thus, it is now possible to:

- reduce the temperature of bituminous mixes,
- preserve their mechanical characteristics and their surface properties,
- decrease the atmospheric emissions, and
- shorten the delays to circulation, under acceptable economic conditions.

The feasibility of these processes has been proven for the development of traditional bituminous mixes to the pure bitumen of grade 35/50 for base or surfacing courses. Some processes are able to produce bituminous mixes containing hard bitumen or binder modified with polymers, and to incorporate recycled materials.

WMA processes truly fit into a sustainable stage of development, and into the new societal values which privilege the environment. WMAs respond to the need to safeguard non-renewable natural resources, conserve energy, and better respect the environment by reducing greenhouse gases and lowering dust rejection. At the same time, they meet performance objectives in conformity with those of hot bituminous mixes, namely in the mechanical properties and for surfaces that are increasingly higher, more general-purpose or more targeted (upper modulus, skid resistance, colours, low noise, reclamation possibilities, etc.).

The follow-up and the technical-economical-environmental evaluation must be continued in order to provide an opinion that is sufficiently reliable and independent to accurately assess the possibilities offered by the warm or semi-warm bituminous techniques. A more global picture will make it possible to better understand their operating mode and to more accurately determine the fields of application.

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