WARM MIX ASPHALT: RUTTING EVALUATION ACCORDING TO TEST CONDITIONS

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ABSTRACT

Nowadays Warm Mixes Asphalt (WMA) in road applications are widely spread out all around the world, using different technologies, in order to reduce mixing and compaction temperatures of Hot Mixes Asphalt (HMA), but still maintaining the same performance. Under a French-Brazilian scientific cooperation among Polytechnic School of University of São Paulo, Brazil (LTP - Laboratorio de Tecnologia de Pavimentação), Ecole Spéciale des Travaux Publics ESTP (IRC-MO), France, and Laboratoire des Ponts et Chaussées in Nantes (now IFSTTAR), France, this paper presents some results of laboratory tests using WMA technology with additive. The temperatures of mixing and compaction were reduced to 120ºC-130ºC and 110ºC-120ºC, respectively. Mix designs were performed with typical materials from France and Brazil: French Béton Bitumineux Semi-Grenu 0/10 and Brazilian Dense Asphalt Concrete 0/10. The asphalt mixture design was done by conventional tests of both countries, such as French gyratory compactor PCG and Marshall method, showing the relevance or not of these tests since considering the reduction of temperature. Rutting tests were carried out according to European standards, with LCPC rutting tester recommended for axel load of 130kN. Variations in test conditions as temperature, plate thickness and also in bitumen grade can distinguish the behavior of WMA from HMA. Tests confirmed that the bitumen extracted from the WMA showed lower aging than HMA. Besides, this study helps pointing out the limitation of some tests due to their conditions for evaluating WMA and also shows the necessity of adapting or even of changing them for new technologies.

KEY WORDS: warm mix asphalt, rutting, temperature, aging.

1 INTRODUCTION

The sustainable development is at the core of the 21st century priorities and efforts have to be provided by each of us to diminish the ecological footprint on the planet. Widely developed in numerous countries, in particular in France and in Brazil, Hot Mix Asphalt (HMA) have seen the temperature of their making of and of their production reduced, due to the development of the Warm Mix Asphalt (WMA) at the beginning of the years 2000. A few years later, numerous construction sites were made with various technologies, which led to energy saving on industrial establishments but also to a reduction of greenhouse gases on the construction sites. Those experimentations were the subjects to some interesting technical synthesis, notably in France. Whether it is the addition of chemical additive or the use of mechanical processes, with wet sand, foamed bitumen or the application of double coating, all those techniques are assessed in laboratory from tests developed on the HMA, according to the standards of each country. How relevant are those conventional tests regarding these new technologies? Do those tests really enable the assessments of the results regarding the temperature lowering? Don’t they need some improvement? It is important to the technician but also to the researcher to know the domain of validity.

That is the aim of the French-Brazilian cooperation between Ecole Spéciale des Travaux Publics of Cachan, LCPC of Nantes (now IFSTTAR) and Polytechnic School of University of Sao Paulo. In order to study the behavior of the WMA in laboratory, the three laboratories join forces into a study which permits the comparison between the French and the Brazilian methods on the process of WMA with chemical additive.
Initiated by a study on the manageability of the asphalts, essential characteristic to insure the laying thus partly to the performance of the asphalt, the work has then led to the rutting resistance. One of the advantages, which is brought to light in the WMA, is the lower aging of the binder due to the lower heating of the basic materials.
But we can also wonder about its impact on the high temperature performance of these asphalts.

2 EXPERIMENTAL PROGRAM AND PROCEDURES

2.1 Materials

2.1.1 Warm asphalt additive

A surfactant compound was added to pure bitumen heated a few minutes before preparing the mix asphalt. The additive rate fixed for the all studies was 0.3% in mass of bitumen. So the bitumen was preheated to 160°C or 165°C and the additive was added on that mass proportion.

2.1.2 Materials

Two types of aggregates commonly used in each country for the producing mix asphalt have been chosen, which are diorite in France and granite in Brazil. Binders were also selected according to each country (all pure bitumens), being 35/50 and 50/70 in France and 50/70 in Brazil.

2.1.3 Mix design and production parameters

The mixtures are classical dense asphalt mixes, being BBSG 0/10 Class 2 (size 0 to 10 mm) in France and CBUQ (size 0 to 12.5 mm) in Brazil.

An important step in the methodology is the determination of the working temperatures, i.e., temperatures for heating aggregates and also bitumen, as well as for preparing the asphalt mix (HMA and WMA). The temperatures are indicated in Tables 1 et 2.

Table 1 - Temperatures in the French study,
in Celsius degrees and in Fahrenheit scale inside brackets

	France					
	BBSG 0/10 with 35/50		BBSG 0/10 with 10/20		BBSG 0/10 with 50/70	
	HMA	WMA*	HMA	WMA*	HMA	WMA**
Bitumen	165 (329)	165 (329)	180 (356)	180 (356)	160 (320)	160 (320)
Aggregates	165 (329)	110 (230)	180 (356)	110 (230)	160 (320)	110 (230)
Compaction / Test	165 (329)	110 (230)	180 (356)	110 (230)	150-160 (302-320)	110-115 (230-239)

* without and with additive
** with additive

Table 2- Temperatures in the Brazilian study,
in Celsius degrees and in Fahrenheit scale inside brackets

	Brazil			
	CBUQ 12.5mm with 35/50		CBUQ 12.5mm with 50/70	
	HMA	WMA*	HMA	WMA**
Bitumen	160 (320)	160 (320)	160 (320)	160 (320)
Aggegates	170 (338)	135 (275)	160 (320)	110 (230)
Compaction test	150 (302)	125 (257)	150-160 (302-320)	110-115 (230-239)

* with and without additif ** with additive

2.2 Evaluation of asphalt

2.2.1 Compaction

The French Methodology is composed by different levels of tests [2]. The first level includes Shear Gyratory Compaction (SGC) and stripping water resistance (also called Duriez test) which isn't present in this paper.

SGC is carried out with a mix prepared in the laboratory mixer, in accordance with the temperature of the bitumen grade (130°C to 180°C) according the NF EN 12-697-3 [3]. The test is sensitive to the proportions of aggregates and to the binder content and can detect sudden changes in the current tests on aggregates. Besides, SGC is used to verify the consistency of the designs over time [2].

On the other hand, Marshall Method was conceived during the II World War and it is still widely used in Brazil, especially by its simplicity and cost. This test is different from the new methods of mixing design by the compaction procedure (gyrations), which is done by impact in Marshall Method [4]. The optimum bitumen content is defined by two principal features: a volumetric criteria and a stability-flow test. In some regions of Brazil, the optimum bitumen content of a dense asphalt concrete frequently is based on the air voids content, which is commonly 4%, by analogy with old American methods.

2.2.2 Rutting

The rutting tests were carried out in France and in Brazil with a MLPC French material [2] described in European standards NF EN 12697-22 [5], as large wheel tracking tester. The European Committee for Standardization recommends the use of the LPC rutting for the network when the legal load is of 130 kN.

There are different rutting processes with specific material, developed by other countries and which requirements differ from the French process. The size of the slabs, the testing conditions (load, frequency, temperature...) and the type of the wheel can differ depending on the types of wheel tracking devices. Thus, Hamburg Wheel Tracking Device (HWTD) is made on 26x32x 4, 8 or 12 cm slabs, compacted at a 7% air void content, with a laboratory compactor or on 15 cm diameter cores. They are immersed in water to undergo 20 000 or 100 000 cycles under a load of 710N and a frequency of 1.13Hz. However, this interesting test has the inconvenience to test two phenomena simultaneously, the resistance to the rutting and the stripping, with the difficulty to separate the influence of each. The tests are running at 50°C in Europe but variants may be applied according to the country.

In the USA, APA (Asphalt pavement Analyzer) has been developed since 1996, enabling the evaluation of the rutting and also other characteristics such as the resistance to water or the fatigue. Normalized (AASHTO TP-63-03), this test can be made on beams or cylinders specimens or construction cores compacted between 3 and 7%, submitted to a steel wheel, under a rubber blown up to 700k Pa and a load of 445 N during 8 000 cycles.
A Canadian comparative study [6] was undertaken on those different equipments and it was important to adjust the testing conditions to have an objective comparison (temperature of the test, type of wheel, water presence or not). It was demonstrated that there are moderate differences on same asphalt according to the process, and it was concluded that only one performing and reliable test was required.

Lately, Perraton and Co [7] published a campaign of comparative tests, undertaken by 3 types of wheel tracking devices described in the European standard and emphasizes on the differences noticed on the different equipments , such as the type of load (load, frequency), of wheel (size, contact surface, hardness of the rubber), of tested plate (size, fixations).

In our study, the specimens for the MLPC rutting test are parallelepiped plate, 50 cm length x 18 cm width, with a thickness of 5 or 10 cm, depending on the asphalt which was tested. They are made with a plate compactor. Tested by pair, they are submitted to a one-wheel traffic load with a frequency 1Hz, a load 5kN, o pressure 6 bars under a high temperature (60°C usually). The depth of the rut on 15 points is provided as per the number of cycles. The specifications describe a rut percentage for a number of cycles given (3 000, 10 000, and more generally 30 000 cycles), which depends on the type and the class of the asphalt.

2.2.3 *Extraction and bitumen recovery*

In order to analyze the bitumen in the asphalt after rutting, a stripping operation is done with a laboratory extractor called asphaltanalyzator as per the European standard NF EN 12697-1[8], completed with an internal procedure of the laboratory, which states the number of washing and drying of the material. The solvent used is the tetrachloréthylène.

The extraction is followed by a recovery of the bitumen from the evaporation of the solvent by rotavapor. The temperature and the pressure are controlled in order to guarantee a complete evaporation without oxidation. The procedure followed meets the European standard NF EB 12697-3[9].

The recovered bitumen is analyzed by the classic tests of characterization of the bitumen (determination of penetrability at 25°C [10] and of the ring and ball softening point [11]).

3 ANALYSIS OF TEST RESULTS

3.1 Compaction

3.1.1 PCG Results

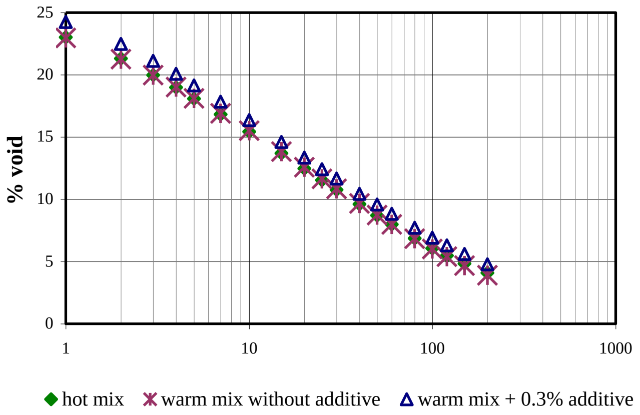

Figure 1- SGC curves for BBSG 0/10 (HMA, WMA with and without additive - 35/50 bitumen)

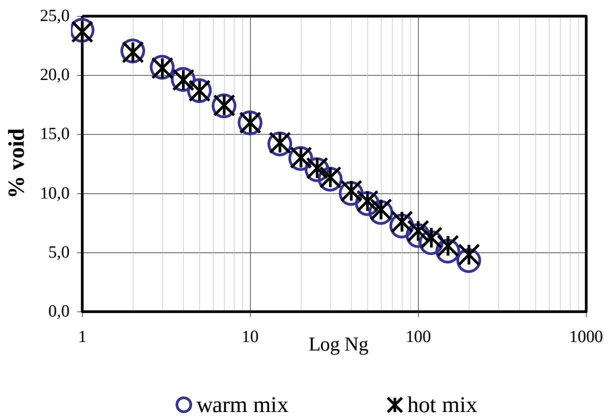

Figure 2- SGC curves for BBSG 0/10 (HMA, WMA with and without additive - 10/20 bitumen)

Experiments conducted on the same BBSG 0/10 formulation shows that the air voids content in the SGC are identical between classical HMA BBSG 0/10 (165°C) and WMA BBSG 0/10 with additive (110°C), as shown in Figures 1 and 2. WMA without additive presented the same SGC compacity as HMA. So the SGC is not enough for showing differences in terms of temperature of the asphalt mix. For all mixtures, the air void contents obtained are in accordance with the French specifications, i.e., between 5% and 10% to 60 gyrations. This optimization of granular recomposition and bitumen content is made by the standardized compaction by means of the SGC, which remains the indispensable basic tool to estimate this granular rearrangement, but whithout taking into account the effects of temperature.

3.1.2 Marshall results

In order to compare HMA and WMA, the air voids content was determined as described in AASHTO T166, using Marshall specimens. The use of a lower temperature for producing warm mixes could impair aggregates coating and turn compaction less effective, culminating in higher air voids content in the asphalt mixture. The mean results are presented in Figure 4.

The results showed that there was a measurable difference in terms of air voids content between HMA and WMA (5.1% and 6.2%, respectively), being the hot asphalt closer to the design air voids (which was set in 4%). So, by Marshall specimens, compaction of WMA seems to have been slightly poorer than the HMA, due to less workability of the asphalt.

Table 3 - Summary of Brazilian asphalt mix design CBUQ with 30/45

Characteristic / Test	Unity	Results	Method
Optimum bitumen content	%	5.0	DNER ME 043
Specific gravity of the bitumen	g/cm^3	1,050	AASHTO T228
Bulk specific gravity of the compacted mix asphalt	g/cm^3	2,385	AASHTO T166
Theoretical maximum specific gravity	g/cm^3	2,491	Asphalt Institute
Air voids content	%	4.2	Asphalt Institute
Voids in mineral aggregate	%	15,1	Asphalt Institute
Voids filled with bitumen	%	71,8%	Asphalt Institute
Indirect tensile strength	MPa	2,10	DNER ME 138

Table 4 - Summary of Brazilian asphalt mix design CBUQ with 50/70

Characteristic / Test	Unity	Results	Method
Optimum bitumen content	%	4.4	DNER ME 043
Specific gravity of the bitumen	g/cm^3	1.010	AASHTO T228
Bulk specific gravity of the compacted mix asphalt	g/cm^3	2.484	AASHTO T166
Theoretical maximum specific gravity	g/cm^3	2.588	Asphalt Institute
Air voids content	%	4.0	Asphalt Institute
Voids in mineral aggregate	%	13.9	Asphalt Institute
Voids filled with bitumen	%	71.1%	Asphalt Institute
Indirect tensile strength	MPa	1.91	DNER ME 138

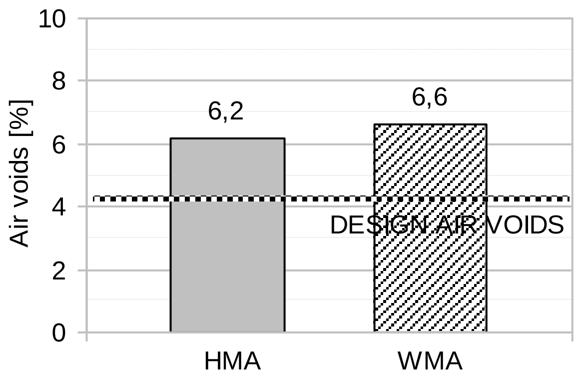

Figure 3 – Air voids content on the Brazilian HMA and WMA with CBUQ 12.5 mm au 30/45

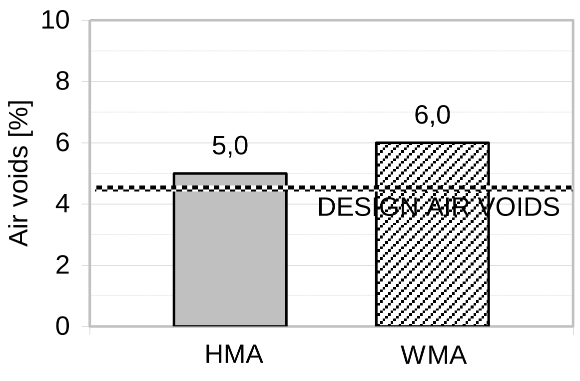

Figure 4 - Air voids content on the Brazilian HMA and WMA with CBUQ 12.5 mm au 50/70

3.1.3 Discussion

The compacity of asphalt is an important indication in order to guarantee its performances especially mechanical ones. It can be obtained through an optimized formulation but also through a correct laying (compliance with the temperatures and wedging of the compaction train).

The SGC test provides the evolution of the compaction asphalt depending on the number of gyration and enables to validate a formulation on the HMA. However, we note that the temperature effect is completely concealed during the test: the level of compaction obtained on a same formulation are identical, for a HMA mixing (165°C) as well as for a WMA mixing (110°C), without or with additive, and this, with two bitumen of different grades, 35/50 and 10/20. Thus, on a construction site, an asphalt of 10/20 with no additive at 110°C would be hardly compactable. Therefore, the PCG test can not be sufficient to measure in laboratory the workability and the level of compaction of an WMA in relation with the reduction of temperature.

Our results, already published at IRF[12], are confirmed by Bennert and Co study [13] also demonstrated the limits of the SGC on the WMA, notably compared with Marshall and to AWD (Asphalt Workability Device: regular speed torque measure in a sample of asphalt of different temperatures), which are more relevant according to them. Morever, Bennert completed her study with usual tests on bitumen such as the viscosity, which also turns out to be insufficient to indicate the profit on workability of some WMA additives. Some current viscosity measures are confirming those characteristics.

3.2 Rutting results

The study has been conducted on French MLPC rutting tester (large wheel tracking tester), by diversifying the test temperature, the thickness of the plate and the grade of bitumen, with French materials as well as Brazilian materials. The table 5 sums up those different aspects.

Table 5 – Variable parameters during rutting tests

Studied variables	Choose of parameters
Asphalt mixing temperature	warm (110°C) or hot (165°C)
Materials nature	French or Brasilian
Bitumen grade	35/50, 30/45 or 50/70
Thickness of plate	5 cm or 10 cm
Rutting temperature	60°C or 70°C

3.2.1 *Influence of thickness of plate*

The European standard recommends rutting tests on 10 cm plates for the BBSG 0/10, laid on job site in a thickness higher than 5 cm, whereas as per Brazilian formulations the tests were made on 5 cm thickness plates.

It should be noted that the aggregates and bitumen used, are not the same in the Brazilian and in the French formulations.

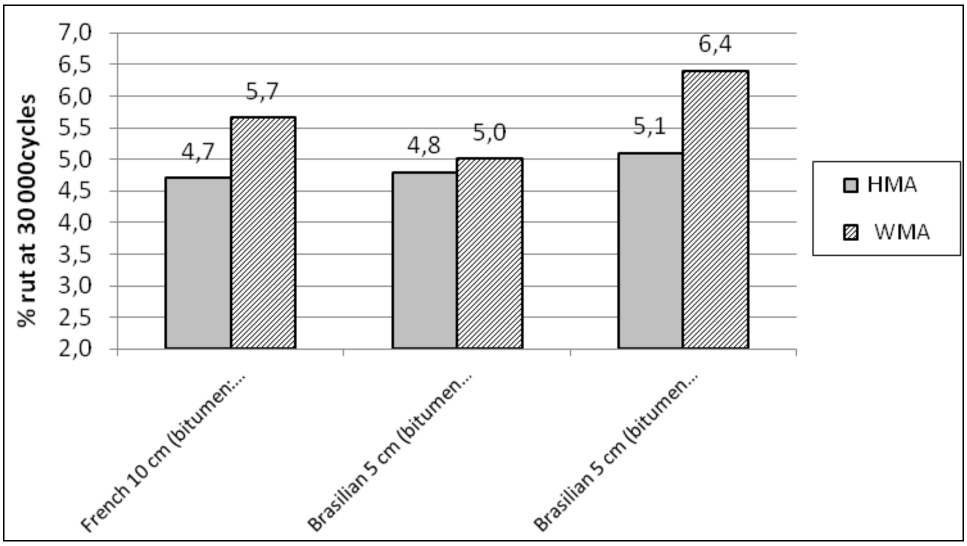

Figure 5 - Comparison of rut % at 30 000 cycles depending on the plate thickness

We can note comparable results between 5 cm and 10 cm plates, the %rut is systematically slightly higher for the WMA than for the HMA.

3.2.2 *Influence of temperature*

The rutting tests were conducted at two different temperatures (60° C and 70°C) on the BBSG 0/10 with 35/50 (French formulation) with and without additive, on 10 cm plates. It is important to note that each result is the average of two plates minimum (6 plates for the tests at 60°C split between two laboratories for compaction as well as rutting, and 2 plates for each test at 70°C). The results are shown on Figure 6.

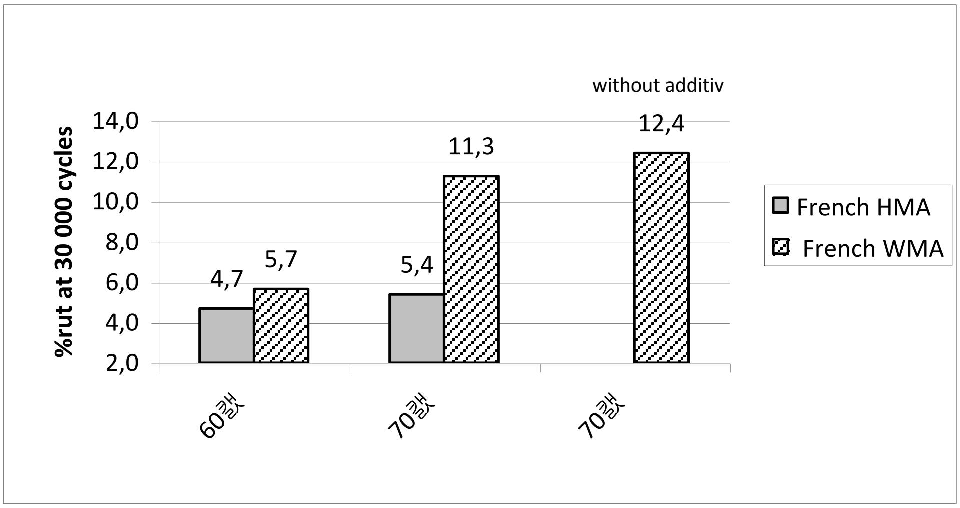

Figure 6 - Influence of test temperature on %rut

Our results made at a conventional temperature of 60°C confirmed the tests published in the French industries and synthesized by Y. Brosseaud in 2007 [1]: the performance of the WHA, tested in accordance with the standard NF 12697-22, leads to a comparable performance to the one of the HMA under the conditions specified, and this with different types of procedures.

The synthesis on WMA of Button and Co [14] led to a more reserved conclusion. This study presented results on WMA by using various types of rutting tests (in particular APA and HWRT). The Hamburg test seemed to show a more important sensibility of the WMA with certain processes according to aggregates and to possible additives but, as we specified it previously, it tests at once rutting performance and the water sensibility with the difficulty to define the influence of every parameter. Besides, the authors specified that the potential of rutting increases with the decrease of the coating and compaction temperatures related with a lesser ageing of the binder.

By modifying the test conditions and making them stricter, we also notice different results with the French rutting tester: by increasing the test temperature of rutting, the behaviour of the HMA and WMA are not identical any more; the depth of rut is slightly superior between 60 and 70°C for the HMA (Δ = 1 %) while it doubles between 60 and 70°C for the WMA and it independently of the added surfactant additive. These results confirm that the ageing of the binder must be lesser.

The interlaboratory test campaign of the technical committee 206 ATB of the RILEM also shows this influence between 50 and 60°C, variable influence according to the type of asphalt [7]. We completed our rutting tests by characterizations of binders, on one hand to estimate the effect of the preparation of the binder before coating and on the other hand the coating and rutting effects in particular the reduction of temperature. The results are presented on figures 7, 8 and 9.

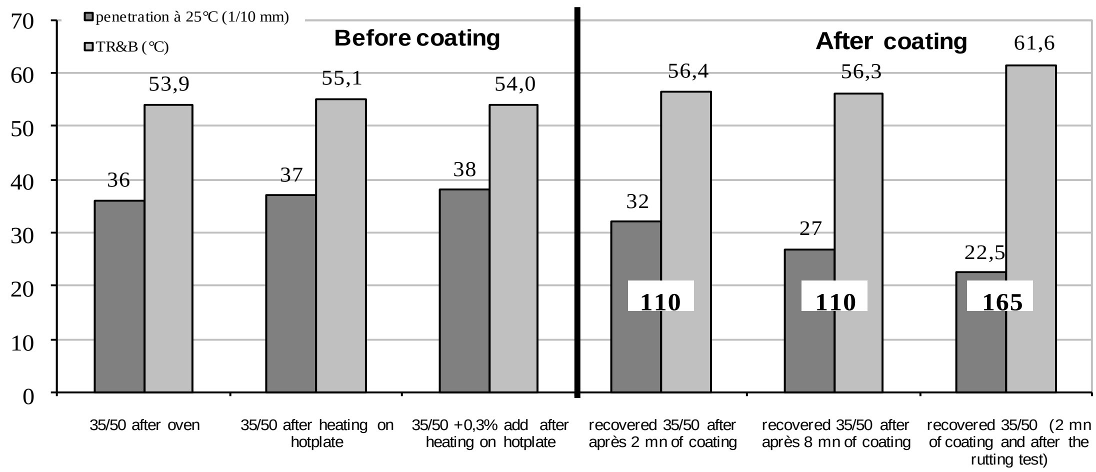

Figure 7 - Penetration and TR&B results of bitumen before and after coating

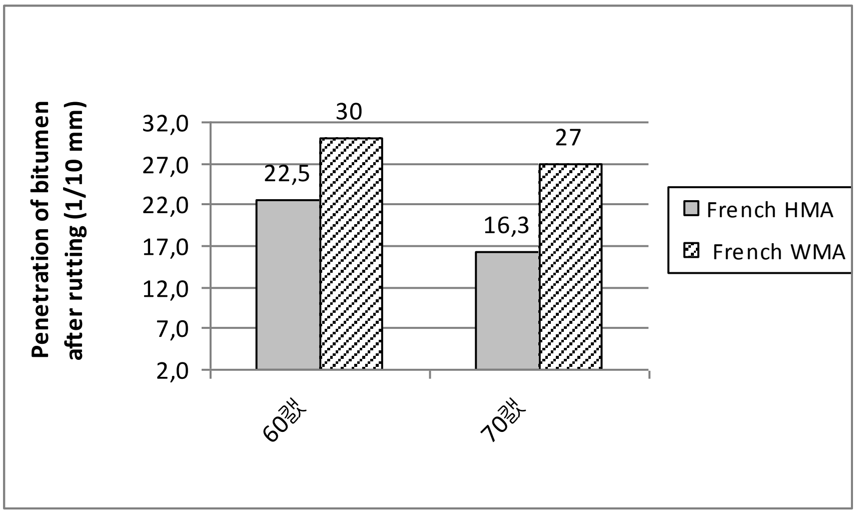

Figure 8 - Influence of rutting temperature on penetration of recovered bitumen

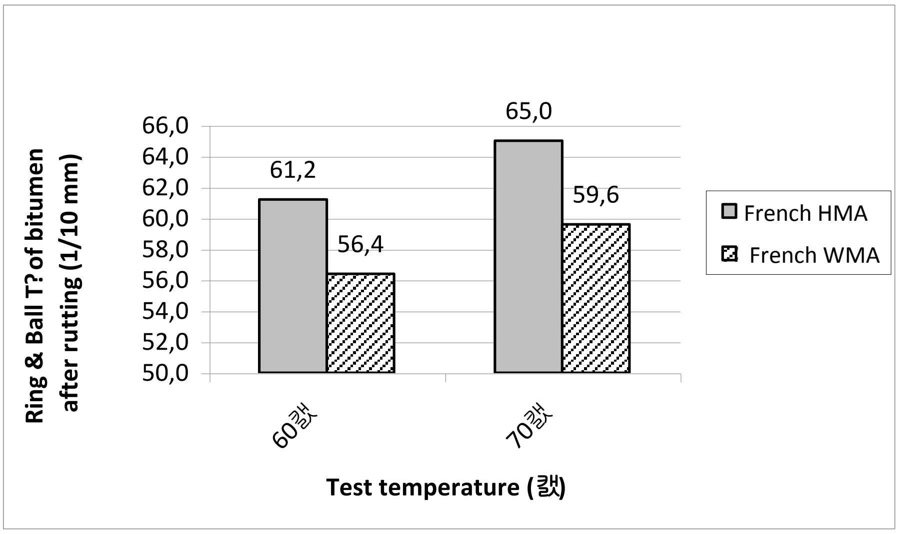

Figure 9 – Influence of rutting temperature on R&B temperature of recovered bitumen

The addition of the additive in binder before coating does not practically influence the characteristics of the binder (penetrability of 37 +/-1 1/10 mm and TR&B of 54.5°C + /-1°C, comparable viscosities). This explains easily by the effect looked for by the surfactant additive: this one has to play on the interfaces with aggregates but without changing the rheologic performance of the asphalt. The temperature of coating has, on the other hand, a significant incidence: a coating at 110°C leads to 35/50 binders with penetrability about 30 1 / 10mm and a TBA lower to 60°C whereas an coating at 165°C leads to a harder binder (< 25 1/10 mm and TBA > 60°C °). For the classic HMA at 165°C, we find the known loss of a class of penetrability for HMA while the loss is lesser on the WMA. According to NGUYEN [15, this influence of the temperature test of rutting is well known and is bound to the thermal susceptibility of the bituminous binder. The more the temperature is raised, the more the binder loses its rigidity and its viscosity, the rigidity of the mixture decreases and the resistance to the permanent deformations, which is assured by the cohesion, also decreases. The asphalt is then more sensitive to the permanent deformations.

The temperature of the rutting test turns out so determining face to face of the performance of the asphalt, in particular between 60°C and 70°C.

3.2.3 Influence of bitumen grade

To verify the influence of the characteristics of the binder on the rutting behavior, we substituted an 35/50 bitumen by one 50/70, in our formulations of asphalt, to be able to reproduce the phenomena observed at 70°C, in standardized conditions of French rutting, namely 60°C.
These tests were led with French formulations (figure-10) and with Brazilian formulations (figure-11).

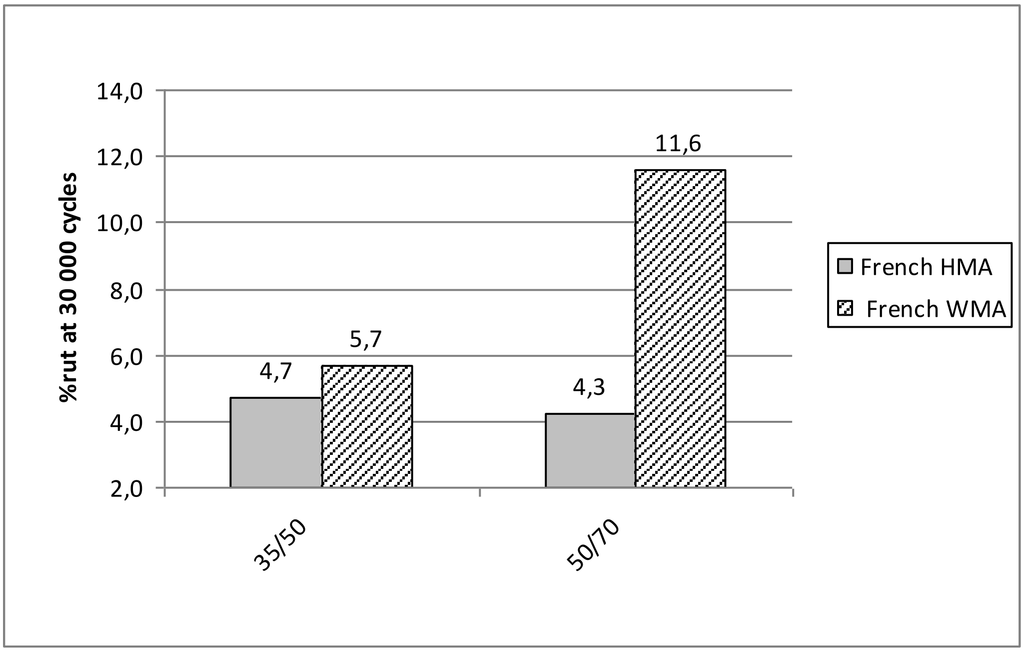

Figure 10 – Influence of bitumen grade on rutting performance in French formulations

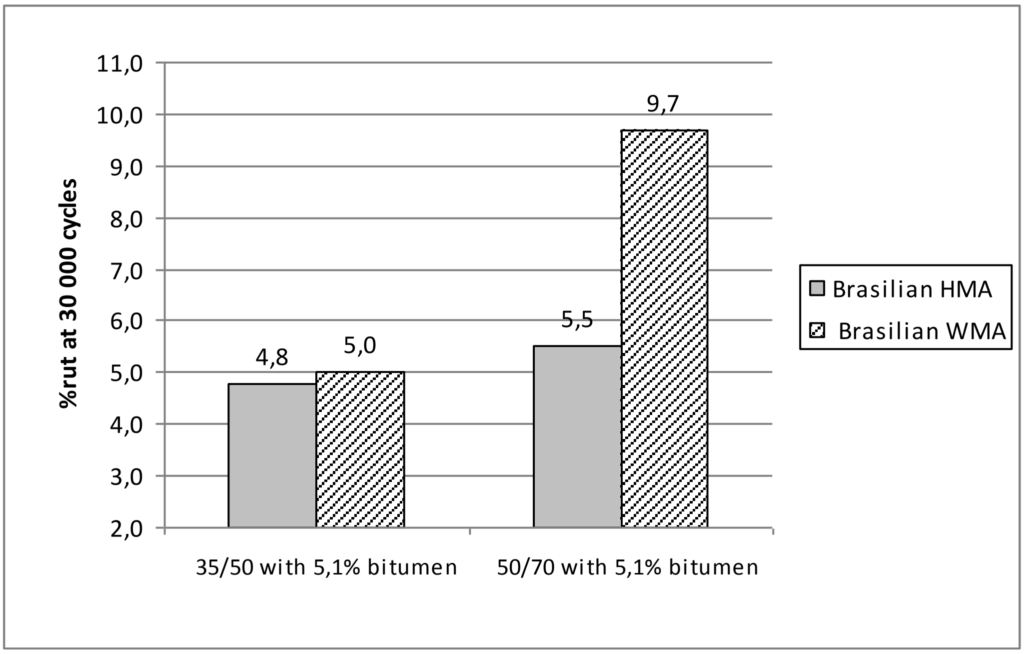

Figure 11 - Influence of bitumen grade on rutting performance in Brazilian formulations

The results obtained on two different formulations, with different aggregates and different bituminous binders are corresponding: the WMA with 35/50 tested in 60°C have an identical performance or slightly more rutting ($\Delta = 0,7$ % max) than the HMA with 35/50. Moreover the WMA with 50/70 present a rutting significantly more important than the HMA with 50/70 (Δ from 4,9 to 5,9 %).
The analyses made on the recovered binders from the asphalt after rutting allow explaining this performance; their results are presented in the table 6. We notice first of all lesser hardenings of the recovered binders of WMA compared with the recovered binders of HMA.
The 50/70 bitumen is initially the highest grade; after extraction from a WMA, it stays much softer than the other binders (penetrability > 35 1/10 mm) and it presents especially a softening point lower and widely lower than the rutting temperature (60°C compared with R&BT of 54,9°C), explaining the performance to the rutting by a more important softening of binder.

Table 6 - Characteristics of recovered binders from rutting plates

	BBSG 0/10 with 35/50		BBSG 0/10 with 50/70	
	HMA	WMA	HMA	WMA
Penetration (1/10 mm)	22,5	27	32	38,1
Δ penentration (1/10mm)	4,5		6,1	
R&B T (°C)	61,2	59,6	58,2	54,9
Δ R&B (°C)	1,6		3,3	

Numerous authors, such as Vanelstraete [16], have already studied, for a long time, the influence of the grade of the bitumen on the performance in the rutting, so showing the interest of a harder binder or modified binder for some HMA to guarantee the good performance in the rutting.

It is thus advisable to optimize the choice of the binder in WMA to take into account its slightest ageing during coating. This one can have positive effects on the durability and also present advantages in fatigue, provided that it does not interfere on the rutting resistance.

4. CONCLUSION

This study had for objective to estimate the relevance of the tests of mix design in laboratory of HMA for WMA‘s processes. It was led on a technique of additivation of surfactant in the binder, thus a simple process not requiring specific mechanical development.

We have interesting conclusions on the determination of the workability and the compaction by SGC, showing that this test allows validating a formulation in the choice of the granular distributions and the binder content but does not turn out sufficient to estimate the effect of the reduction in the temperature on the level of compaction. The results of the University of Sao Paulo seems to show besides that the Marshall test leads to minor differences (increase of 1% of air voids) between HMA and WMA. These conclusions already published by the other researchers [18] can explain by the difference of both tests, in particular the application of the load between SGC (compaction by “kneading”) and the Marshall (compaction by impact). It is however important to remind that the) the Marshall presents limits for the formulation of the hot mix asphalt in particular its relevance with regard to the construction site. A thought must be thus led to estimate the effect "reduction of temperature" towards the workability of asphalt while preserving the SGC for the validation of the mix design. The study of rutting had not for objective to contradict this well known test, judged relevant and severe with regard to the performance of asphalt on roads. It however allowed us to bring to light the differences of performance of the hot and warm mix asphalt at the high service temperatures: by changing the test temperatures and the grade of the binder. It validates the slightest hardening of the binder in WMA, already often advanced by many authors. Thus the choice of the binder in some of these processes must be made sensibly to avoid possible permanent deformations of the asphalt at the young age, on road with high stresses. Complementary rheologic tests on the recovered binders would besides allow to complete this study. The ageing of the binder in WMA, during the coating, is certainly different from that of the same binder in HMA. From now on researches in this domain seem indispensable to understand the performance of the binders in these new asphalt because it determines the long-term performances of the asphalt.

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