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# French wheel tracking round robin test on a polymer modified bitumen mixture

## RILEM TC 206-ATB, TG3: Mechanical testing of mixtures

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**Abstract** In the framework of the RILEM TC 206-ATB TG3, a Round Robin Test (RRT) has been performed in order to evaluate the reproducibility of the French Wheel Tracking Test (FWTT) on a mix made with Polymer Modified Bitumen (PmB). For this mixture, some particular problems had been reported, such as heating of the sample due to friction and sticking of the binder to the wheel. Two procedures, called anti-overheating and anti-sticking procedures, have been proposed by the group in order to improve the reproducibility of the wheel tracking tests. These procedures are assessed. Causes of scattering are discussed. Differences between the tyres used during this RRT as a possible origin of

scattering are discussed, as well as temperature peaks and over-compaction of specimens.

**Keywords** Rutting · Round Robin Test · Polymer modified bitumen · French Wheel Tracking Test · Experimental

### 1 Introduction

The French Wheel Tracking Test is designed to qualify bituminous mixtures according to their capacity to resist to rutting. It is an integral part of the French Design Method for pavement design [3, 8, 16]. The test procedure has been standardized in Europe by the EN 12697-22. This test has been originally designed to qualify hot mix asphalts made with pure bitumen. Nowadays, other types of processes are also used, like warm, half-warm and cold mix asphalts. Even when only considering hot mix asphalts, numerous types of Polymer modified Bitumen (PmB) are used, especially for thin surface layers. EVA polymer (Ethyl-Vinyl-Acetate), and plastomeric bitumen in general, was used to avoid risks of rutting [10]. Softer bitumen can be used, considering that the polymer increases stiffness at high temperature and reduces bitumen thermo-susceptibility.

In the framework of the RILEM Technical Committee “Advanced Testing of Bituminous Materials”, the main purpose of Task Group 3 was to study tests for permanent deformation appearing in bituminous

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\*This Round Robin Test was developed by the Task Group 3 within RILEM TC 206-ATB under the leadership of Prof. Hervé Di Benedetto,

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RILEM Technical Committee 206-ATB, TG3

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mixtures under cyclic loading. Previous studies have focused on visco-elasticity [4] and fatigue [5]. This paper is concerned with permanent deformation appearing in bituminous mixtures under cyclic loading. It summarises some results obtained by the group between 2006 and 2009. The French Wheel Tracking Test apparatus and its capacity to predict in a reproducible way the rutting behaviour of bituminous mixtures containing polymer modified bitumen is assessed.

A first experimental program carried out by TG3, named “Campaign A” has highlighted differences between results from different rutting tests carried out with different types of WTT (wheel tracking test) devices. Tests have been performed on Asphalt Concrete (AC) with pure bitumen. The obtained results, presented in Perraton et al. [14], have shown that the rut depth strongly depended on the type of apparatus. In the case of pure bitumen mixes, FWTT results are rather well reproducible, as confirmed in Perraton et al. [14]. Meanwhile, some laboratories encountered specific sticking problems for highly modified Pmb’s that induced large variability of results [2]. Then a second RILEM campaign presented in this paper, named campaign B, has focused on one type of apparatus, the French Wheel Tracking Test device. The purpose of this is to evaluate the reproducibility<sup>1</sup> of tests with the FWTT devices, on chosen polymer modified bitumen mixture (AC-PmB) described hereafter. Therefore, a RRT has been undertaken. Plates of the same AC-PmB were made by one laboratory and sent to the participating laboratories before being tested on the FWTT devices.

## 2 Round Robin Test on the FWTT device

### 2.1 Material, specimen and performed tests

#### 2.1.1 Material design

The asphalt concrete (AC) tested in this study is made with a plastomer type polymer modified binder. The constituents are presented in Table 1 and the grading curve is given Fig. 1.

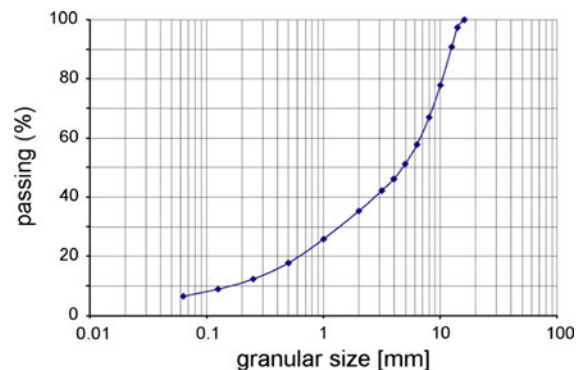
<sup>1</sup> Reproducibility is defined as the capability to reproduce tests in different laboratories.

**Table 1** Mix design of the asphalt concrete tested in this study

Origin quarry	Class (mm)	Mass ratio (%)	Bulk density
Noubleau	10/14	23.5	2.889
Noubleau	6/10	22	2.829
Noubleau	4/6	10	2.833
Noubleau	2/4	11	2.863
Cusset	0/2	32	2.690
Airvault	Filler	1.5	2.706
Total Agg.		100	
Binder (50/70 PmB EVA)		5.55 <sup>a</sup>	
Total		105.55	

Binder content is expressed in terms of external percentage

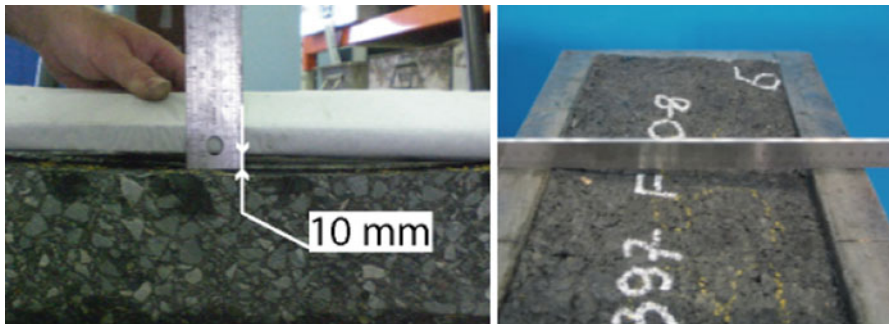
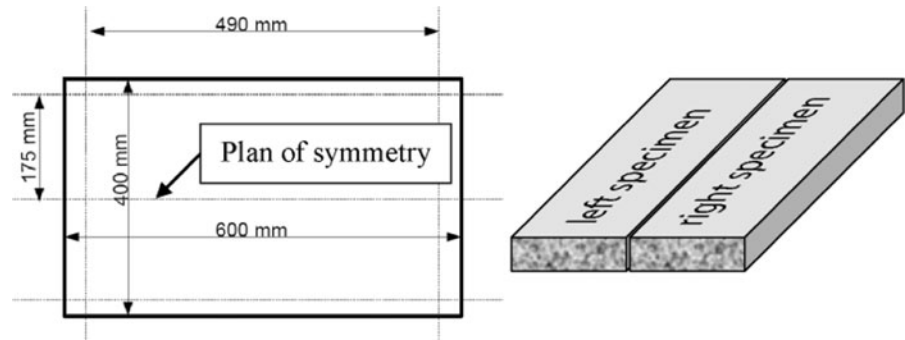
<sup>a</sup> Part by weight of aggregate



**Fig. 1** Grading curve of the aggregates of the mix design of this study

Coarse Aggregates have been extracted from the Noubleau quarry (France), the fine aggregates (particles less than 2 mm) and the filler came from, the Cusset quarry (France) and the Airvault quarry (France) respectively. The mineralogical nature of Noubleau, Cusset and Airvault quarries are diorite (igneous rock), andesitic tuff (igneous rock) and limestone (sedimentary rock) respectively. The sand (0/2 mm) from Cusset quarry has been milled by means of a rod mill. This sand is more rounded than typical crushed sands, which means that the mixture is more sensitive to rutting [11]. The binder is a polymer modified bitumen. The polymer added in the bitumen is an Ethyl-Vinyl-Acetate one (EVA), which is plastomeric in nature. The considered mixture can be classified as a BBSG (Béton Bitumineux Semi-Grenu), according to the French Standard.

**Fig. 2** A big manufactured slab gives two specimens tested with the FWTT device



**Fig. 3** Problems observed during slab compaction phase: for a size of  $490 \times 175 \times 100$  mm, a settlement of 10 mm in the middle of the slab can be observed for some slabs

## 2.1.2 Specimen manufacturing

**2.1.2.1 Slabs manufacturing** AC slabs have been manufactured in laboratory according to the standard EN 12697-33 using the French roller compactor according to a “strong” compaction schedule. All the slabs have been prepared in the same laboratory (LCPC Nantes), in order to avoid problems of reproducibility in manufacturing. However, for practical reasons and in order to limit the quantity of slabs to manufacture, it has been decided to prepare big slabs  $600 \times 400 \times 100$  mm, that were then cut into two specimens to be tested with the FWTT device ( $490 \times 175 \times 100$  mm) (see Fig. 2).

**2.1.2.2 Remarks on the compaction phase** During the compaction phase using the French roller compactor, slabs have shown a “mattress effect” (bumps can be observed around the wheel). Samples behave like fine saturated soils. This behaviour during compaction is usually observed when the bituminous mixture has reached a high level of compaction. As a result, slabs have exhibited a curved top surface

instead of the expected flat surface (see Fig. 3). Over a length of 490 mm, the curvature depth could reach as much as 10 mm. This was also found to occur more in the middle of the slab than at the edges.

**2.1.2.3 Density analysis** A measurement of void content (void volume in percent of total volume) of two specimens coming from one slab has been performed by Lab1 (cf. Table 5). Gamma rays have been used to assess the void content, according to the standard EN 12697-7 [9]. Results are presented in Table 2.

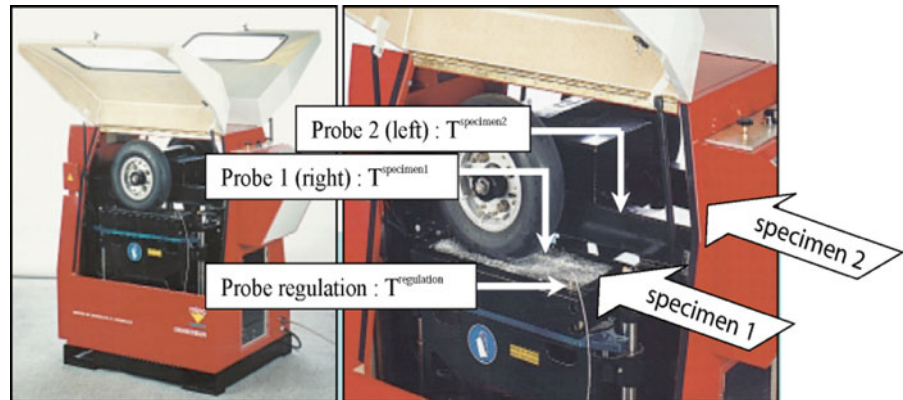
According to the standard EN13108-1, annex E, porosity for such a material is expected between 4 and 8%, for a good behaviour on site. The obtained mean value shows that our material is over compacted, which makes it more sensitive to the rutting phenomena.

## 2.2 The French Wheel Tracking Test (FWTT)

The French Wheel Tracking Tester is a piece of laboratory equipment designed to investigate the

**Table 2** Theoretical void content and measured void content of an AC slab

	Target (%)	Specimen 1 (%)	Specimen 2 (%)	Mean value (%)
Void content	4–8	2.3	3.0	2.7

**Fig. 4** French Wheel Tracking Test. Position of probes

rutting resistance of bituminous mixtures under conditions of stress and temperature that aims simulating the conditions applied to pavement, in accordance to the standard EN 12697-22 [8]. Parallelepipedic specimens of bituminous mixes are subjected to repeated passes of a wheel fitted with a tyre, mounted on a carriage that moves back and forth at a sinusoidal rhythm, inducing permanent deformation (see Fig. 4). Two specimens can be placed in the FWTT at a time, on two separate supports, for testing with the same parameters, under the same temperature conditions. A full description and a video of this apparatus can be seen on the LCPC website.<sup>2</sup>

### 2.3 Anti-overheating and anti-sticking procedures

Some laboratories have encountered problems of overheating of specimens and sticking between tyre and specimen during previous rutting tests [2]. These two phenomena led the maximum temperature allowed in the standard being exceeded, which made test results to be considered as “out of standard”. Even though from discussions within the group it appeared that sticking problems were noticed by only a few number of the participants, two specific

procedures, an anti-sticking and an anti-overheating procedure have been proposed in order to mitigate against these problems. The RRT was organized to assess the potential of these procedures to prevent these phenomena and to limit the scattering of the results obtained by the different laboratories, leading to a general improvement of the reproducibility of the test method. These procedures are described in the following sections.

#### 2.3.1 Anti-overheating procedure

For FWT tests on a classical material, no overheating is usually observed. The following procedure has been specifically developed in this RRT to prevent overheating.

A FWTT device with four temperature probes is considered: two probes enable respectively to measure the temperature ( $T^{\circ\text{C}^{\text{specimen1}}}$ ) of specimen 1 (right) and temperature ( $T^{\circ\text{C}^{\text{specimen2}}}$ ) of specimen 2 (left). These probes are installed in the middle of the slabs, just beside the wheel path, at the inner side of the machine, which are the places where the highest temperatures are normally expected. Another probe put inside the specimen 1 is used to regulate the temperature of the thermal chamber and another probe enables to measure the air temperature inside the thermal chamber (see Fig. 4). For a test performed at 60°C (resp. 50°C), this procedure aims at

<sup>2</sup> [http://www.lcpc.fr/en/produits/materiels\\_mlpc/fiche.dml?id=123&type=abcaire](http://www.lcpc.fr/en/produits/materiels_mlpc/fiche.dml?id=123&type=abcaire)

**Table 3** Anti-overheating procedure for tests respectively performed at 60°C (respectively 50°C)

Test launching	
Condition 1	If $T^{\circ}C^{\text{specimen1}}$ or $T^{\circ}C^{\text{specimen2}}$ reaches 62°C (resp. 52°C) while increasing :
Step 1	Loading and thermal chamber regulation (heating) are both stopped. FWTT device doors are opened
Step 1 bis	If anti-sticking procedure, spread GSO (Glycerized Sodium Oleate) and/or place new paper if necessary
Condition 2	When $T^{\circ}C^{\text{specimen1}}$ or $T^{\circ}C^{\text{specimen2}}$ reaches 58.5°C (resp.48.5°C) while decreasing,
Step 2	The doors of the FWTT are closed, the thermal chamber regulation (heating) is restarted, the regulation temperature for the chamber is fixed at 58.5°C (resp. 48.5°C)
Condition 3	After 45 min of regulation (to let specimens reach thermal equilibrium before reloading it!)
Step 3	Cyclic loading is restarted at a regulation temperature of ( $T^{\circ}C^{\text{regulation}}$ ) 58.5°C (resp. 48.5°C)

**Fig. 5** Anti-sticking procedure. It consists of placing a sulfurized paper on the top surface of the specimen and spreading a greasy soap on it and on the tyre

keeping the temperatures measured inside the samples between 58°C (resp. 48°C) and 62°C (resp. 52°C) throughout the test. This is described in Table 3.

### 2.3.2 Anti-sticking procedure

This procedure has mainly been developed at LCPC by Vincent Dubois, after observing sticking problems during previous tests on AC-PmB. It consists of lubricating the tyre with a mixture of Glycerized Sodium Oleate (GSO). GSO is a highly greasy soap. In addition, a “sulfurized paper” (cooking paper) is laid on the specimens and also pasted with GSO. Each time the door of the thermal chamber of the apparatus is open, the paper is checked. If damaged it is changed and GSO is spread on it and on the tyres (see Fig. 5). The apparatus can be opened either in order to carry out measurement or to follow the anti-overheating procedure.

## 2.4 Description of the Round Robin Test

All the tests have been performed following the anti-overheating procedure, as closely as possible. Seven laboratories took part in the RRT, namely in an

**Table 4** Tests dispatched between the different laboratories

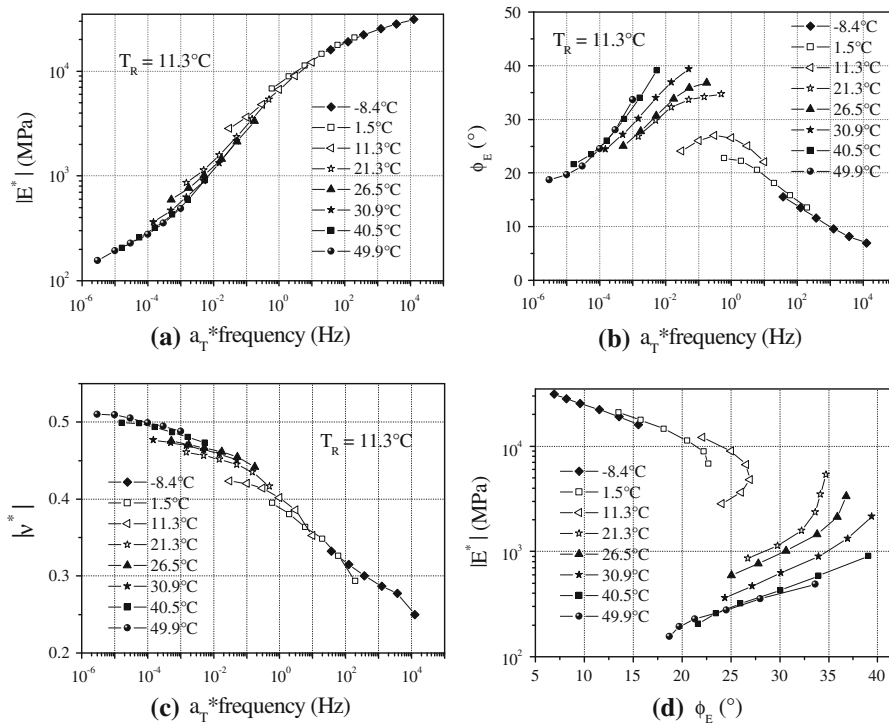
Test	Lab							
	1	2	3	4	5	6	7	8
50°C AS0	2	2		2				
50°C AS1		2					2	
60°C AS0		2	2	2	2 <sup>a</sup> + 2 <sup>a</sup> + 2 <sup>a</sup>		2	
60°C AS1	2 + 2 <sup>b</sup>		2 + 2 <sup>c</sup>	2			2	2
Rheological tests								2

The figures indicate the number of tested specimens; one test needs two specimens (1 slab). AS0 means “without anti-sticking” and AS1 means “with anti-sticking”

<sup>a</sup> Test performed with two different tyres (from lab5 and lab2)

<sup>b</sup> Test performed with two different tyres (from lab1 and lab2)

alphabetical order, BRRC (Belgium), ENTPE (France), EIFFAGE Travaux Publics (France), IBDiM (Poland), LCPC (France), LUCREB (Québec), NTEC (UK), TOTAL (France). In this paper laboratories are identified by numbers in random order that keep them anonymous. It was decided to perform tests both at 50 and 60°C. Table 4 describes how the tests have been performed in the different laboratories. One



**Fig. 6** Results of complex modulus tests on the PmB mixture; master curves of: norm of complex modulus (a), phase angle of complex modulus (b), norm of complex Poisson's ratio (c) and Black diagram of complex modulus (d)

FWTT needs two specimens (left and right on the device), and therefore one “big” slab.

### 3 Results

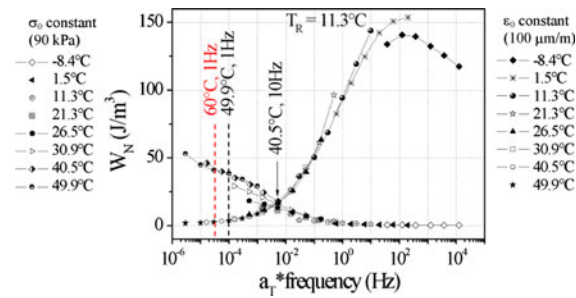
#### 3.1 Complex modulus results

Tension–compression complex modulus tests have been performed by University of Lyon/ENTPE in order to quantify viscoelastic characteristics of the tested PmB material. Test results are presented in Fig. 6, for both complex Young's modulus ( $E^*$ ) and complex Poisson's ratio ( $\nu^*$ ). The three plotted master curves use the same shift factor, which is a first noticeable result. This figure also highlights that such PmB mix doesn't follow the Time–Temperature Superposition Principle (TTSP), as a unique curve is not obtained in the Black representation (Fig. 6d). Meanwhile the so called “Partial Time–Temperature Superposition Principle” (PTTSP), as defined by Olard et al. [13] can be considered because the shifting procedure gives a rather unique master curve

only for the norm of the modulus (and not the phase angle). It can also be observed Fig. 6c that the PTTSP can be considered for the Poisson's ratio.

It is well known that rutting process is much more important at high temperatures (above 40°C). For this range of temperatures EVA Polymer has an important influence as can be deduced from the shape of the Black curve. This influence is mainly characterised by, (i) a decrease of phase angle with temperature and frequency, and (ii) the influence of the temperature on the shape of the curve when changing frequency (TTSP not respected).

As clearly shown further in this paper, temperature increases during wheel tracking test (WTT), which is a strong biased effect of the test. This increase is due to viscous dissipated energy that is transformed into heat [1, 6, 12]. In order to evaluate this increase, Fig. 7 gives the values of the viscous dissipated energy per cycle and unit volume ( $W_N$ ) (Eq. 1) for each considered experimental frequency and temperature. The two plotted master curves in Fig. 7 represent results for cycles at constant strain amplitude ( $\varepsilon = 100 \mu\text{m/m}$ ) and cycles at constant stress



**Fig. 7** Master curves of viscous dissipated energy per cycle  $W_N$  at a reference temperature ( $T_R = 11.3^\circ\text{C}$ ) for two cases: strain control tests ( $\epsilon_0 = 100 \mu\text{m/m}$ ) and stress control tests ( $\sigma_0 = 90 \text{ kPa}$ ). Tests are the same as Fig. 6

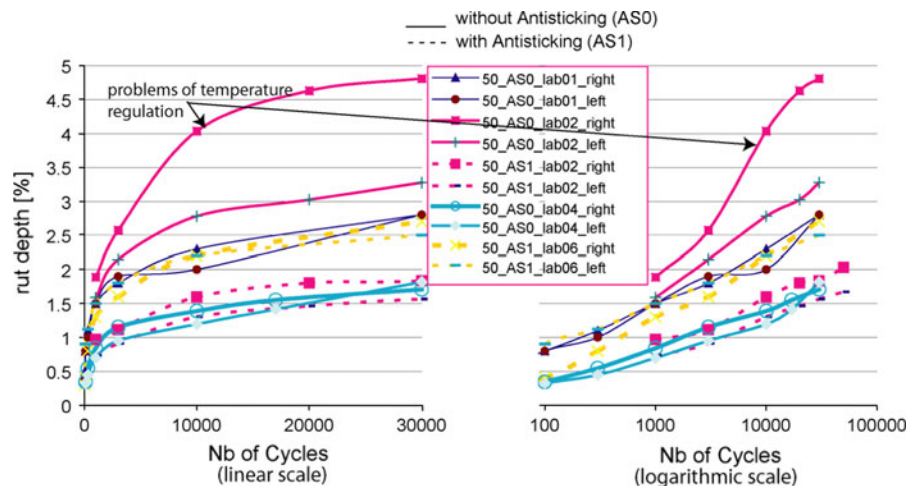
amplitude ( $\sigma = 90 \text{ kPa}$ ). The shift factor used for master curves of Fig. 6 is considered.

$$W_N = \pi \sigma \epsilon \sin(\varphi) \tag{1}$$

$W_N$  is the dissipated energy per cycle and unit volume at cycle  $N$ , where strain amplitude, stress amplitude and phase angle are  $\epsilon$ ,  $\sigma$ ,  $\varphi$ , respectively.

Figure 7 reveals that TTSP is valid for  $W_N$ . In this figure the two values of ( $50^\circ\text{C}$ , 1 Hz) and ( $60^\circ\text{C}$ , 1 Hz) are indicated. These two values correspond to the temperatures and frequency considered during the WTT campaign. As WTT is a stress controlled test (a constant load is applied to the wheel that creates an average pressure of 600 kPa at the surface), emphasis should be given to stress control master curve. Dissipated energy at 50 and  $60^\circ\text{C}$  for stress control tests at 1 Hz are rather high, which explains why heating is so important for this kind of materials.

**Fig. 8** Rutting tests performed at  $50^\circ\text{C}$ , right and left rut depth values. Both linear and logarithmic scales are presented



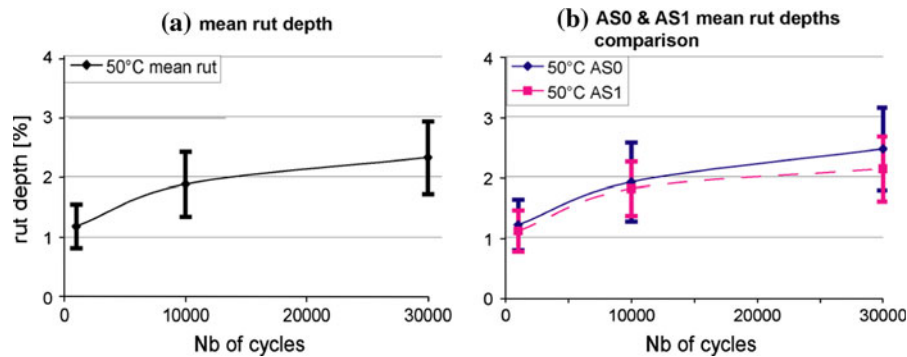
The results presented in this section are considered for FEM calculation of FWTT performed by a sub-team of Rilem TC-ATB TG3, which is not presented in this paper.

### 3.2 Rutting tests at $50^\circ\text{C}$

Results of RRT performed with the FWTT at  $50^\circ\text{C}$  are presented in Fig. 8 (left and right specimens), with the rut depth in percent plotted as a function of the number of cycles. Rut depth is plotted as a function of the number of cycles on both a linear and a logarithmic scale. Full lines represent tests performed *without* the anti-sticking procedure (AS0), whereas dashed lines correspond to tests performed *with* the anti-sticking procedure (AS1).

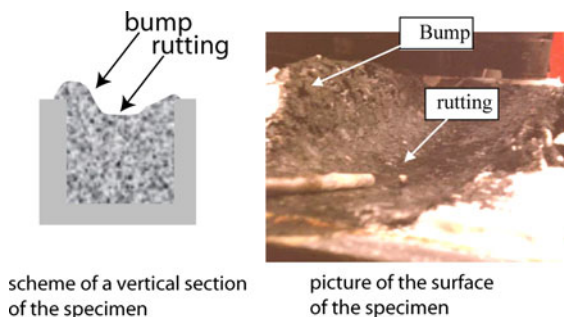
The left and right results are quite similar for each laboratory, except for lab2 (results AS0-lab2). A failure of the temperature probe was noticed during this test, which is perhaps responsible for the higher level of rutting observed on the right specimen. It is possible that the right specimen has been submitted to higher overheating, but heterogeneity of the test specimen could also explain the difference. In the following analysis, this result (AS0-lab2-right) is not taken into account. In Fig. 9a, the mean rut depth and standard deviation of all tests performed at  $50^\circ\text{C}$  is presented. In Fig. 9b, a comparison of mean AS0 and mean AS1 results is shown. At 30,000 cycles, rut depths vary between 1.5 and 3.3%. AS1 results (dashed lines) seem to be lower (13% maximum of difference) and less scattered (20% maximum of difference) than AS0 (full lines) ones. However,





**Fig. 9** a Mean rut depth values for all tests performed at 50°C. b Comparison of AS0 (without antisticking) and AS1 (with antisticking) results at 50°C, in terms of mean values and

standard deviations. All results of Fig. 8 are considered except AS0-lab2-right



**Fig. 10** An important bump can be observed for the “60\_AS1\_lab6\_right” result

according to the number of results this difference cannot be considered to be significant. The comparison between AS0 and AS1 results will be discussed in Sect. 3.4.

### 3.3 Rutting tests at 60°C

Results of RRT performed with the FWTT at 60°C are presented in Figs. 11 and 12. The rut depth (in percent) is a function of loading cycles. Both linear and logarithmic scales are plotted for the number of loading cycles. Full lines represent tests performed *without* the anti-sticking procedure (AS0), whereas dashed lines represent tests performed *with* the anti-sticking procedure (AS1). In Fig. 11, the rut depth measured for each specimen, left and right, is plotted. In Fig. 12, each result is a mean value of rut depths measured under the left and right tyres.

One specimen, AS1lab6 right, has shown very significant rutting, with upheaval observed at the

edge of the wheel track. According to the observed curved top surface of the slab, this specimen was probably over-compacted before test. It has not been considered for the presented analysis (see Fig. 10).

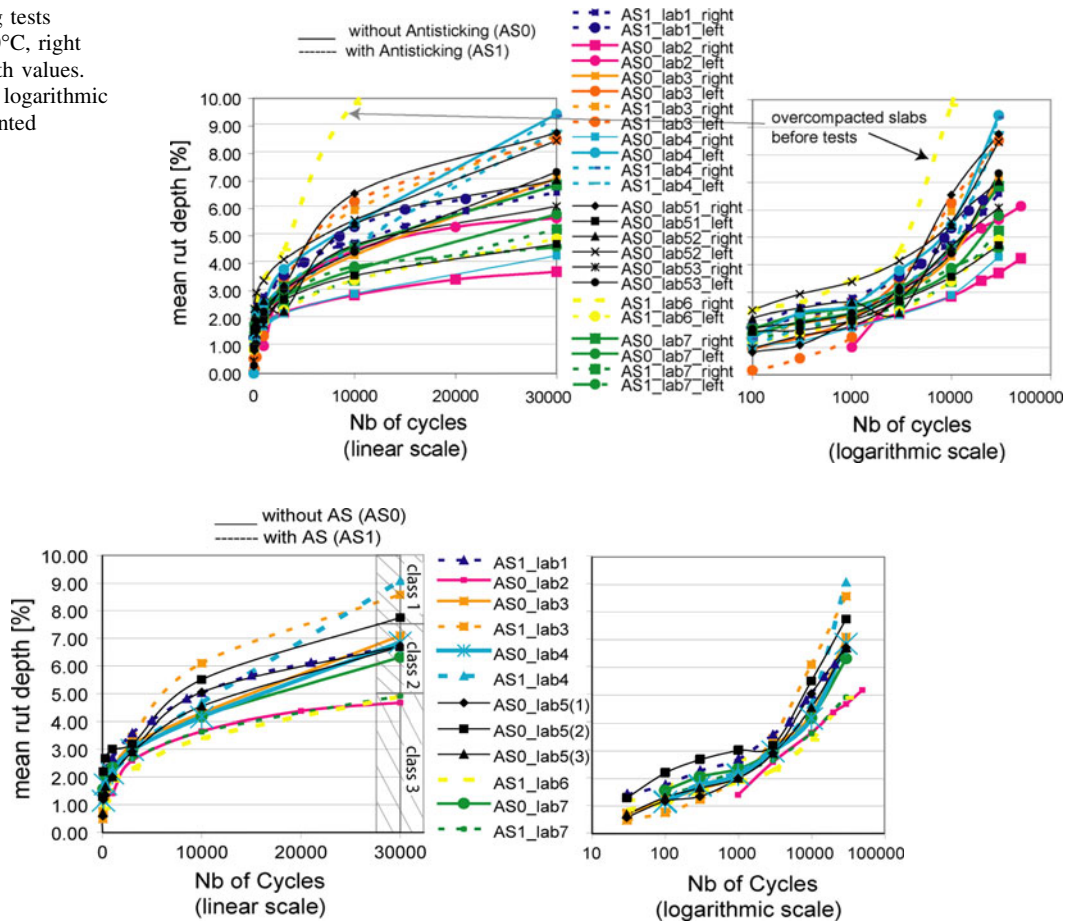
Lab1 AS1, lab3 AS1, lab4 AS1, lab5 (2 and 3) AS0, lab6 AS1 and lab7 AS1, give similar results for the left and right specimens. At 30,000 cycles, an important difference is observed for lab4 and lab6 for the procedure without antisticking (AS0 results) between left and right results. However, in most of cases, differences do not exceed 2% of rut depth at 30,000 cycles.

The reproducibility  $R$  of the RRT has been assessed. It is defined as:

$$R = 1.96 \sqrt{2\sigma_R^2}, \quad (2)$$

where  $\sigma_R$  is the standard deviation of all the tests performed. Results are presented Table 5. The reproducibility “ $R$ ” of our tests is higher than the one given by the standard, which indicates less reproducibility. It has to be reminded that the values given in the standard are based results of a RRT performed in 1992, involving twelve laboratories, using specimens of a typical French asphalt concrete, manufactured by a unique laboratory. The results are quantitatively more comparable to those obtained during the last French Round Robin Test, performed in 2010, involving 33 laboratories, also using specimens of a typical French asphalt concrete, manufactured by a unique laboratory (see Table 5). This second comparison seems to be more appropriate, because tests are quite recent. According to these results, it can be concluded that test performed on PmB-AC are of the

**Fig. 11** Rutting tests performed at 60°C, right and left rut depth values. Both linear and logarithmic scales are presented



**Fig. 12** Rutting tests performed at 60°C, mean rut depth values. Performance class considering French design method are also indicated

same order of reproducibility than those performed on typical asphalt concrete without polymers.

As modulus at 15°C and 10 Hz is higher than 7000 MPa (Fig. 6), the material could be classified according to French standard “NF EN 13108-1” as a BBSG of class 2 or 3. WTT results at 60°C presented Figs. 12 13 and 18, indicate that it should be ranked either in class 1, 2 or 3, following the laboratory and the type of tyre.

The comparison of AS0 and AS1 results will be discussed in the following section.

### 3.4 Anti-sticking procedure

At 50°C, results with and without the anti-sticking procedure are compared in Fig. 9. Lab2 has performed tests both with and without the anti-sticking procedure. According to these results only, the anti-

sticking procedure seems to slightly decrease the level of rutting. However, according to the results of all participants, AS0 and AS1 results are of the same order of scattering and mean values. The conclusion is therefore that no significant influence of the anti-sticking procedure can be observed.

At 60°C, results with and without anti-sticking procedure are compared in Fig. 13b. Lab3, Lab4 and Lab7 have performed tests both with and without the anti-sticking procedure. According to results presented in Figs. 11, 12 and 13, the anti-sticking procedure tends to increase the level of rutting for lab4, which is not an expected result. For lab7, this procedure seems to decrease the level of rutting. For lab3, one of the two specimens tested at 60°C without the procedure showed sticking with the tyre and reached such a high level of rutting that this rutting was impossible to measure. Thus, no trend can be



**Table 5** Comparison of AS0 and AS1 results (resp. 14 and 9 results) at 60°C, in terms of mean values, standard deviations and variances

Nb of cycles	1000	3000	10,000	30,000
Mean rut depth (%) AS0	2.14	2.97	4.50	6.55
Variance AS0	0.30	0.32	1.16	3.03
Standard deviation AS0	0.55	0.57	1.07	1.74
Mean rut depth (%) AS1	2.26	3.10	4.70	7.06
Variance AS1	0.20	0.24	1.05	3.40
Standard deviation AS1	0.45	0.49	1.03	1.85
Mean rut depth (%)	2.19	3.02	4.58	6.76
Standard deviation	0.50	0.53	1.03	1.76
Reproducibility	1.40	1.48	2.90	4.92
Standard reproducibility [8]	0.97	1.32	1.20	1.16
Last RRT reproducibility [15]			3.88	4.59
$t$ -test : $\text{mean}_{\text{AS0}} = \text{mean}_{\text{AS1}}$	0.58	0.54	0.67	0.52
$p$ -value				

The  $t$ -test cannot show any significant difference between the mean values of AS0 and AS1 results

seen considering the influence of the anti-sticking procedure on results lab by lab. It can however be noticed that without anti-sticking procedure, sticking can be observed.

A comparison between the mean AS0 rut depths and the mean AS1 rut depths is presented in Fig. 13. Standard deviations intervals are also plotted in this figure. It reveals that the average values of AS1 slightly show more rutting than those of AS0. This result is opposite to what some of us were expected. A statistical  $t$ -test has been performed to analyse the data (see Table 5). The “null hypothesis” ( $H_0$ ) of this test is: mean rut (AS0) = mean rut (AS1). As the  $p$ -value is far from 0.05 (0.56–0.67 according to the

number of cycles) whatever the number of cycles, the  $H_0$  hypothesis cannot be rejected. Then, from a statistical point of view, the results of this test do not show any significant difference between tests without anti-sticking (AS0) and tests with anti-sticking (AS1).

A comparison of the standard deviations has also been performed and does not show any significant trend to limit the scattering of results with the anti-sticking procedure. It can however be noticed that this procedure tends to decrease the scattering between the left and right specimens during each AS1 test.

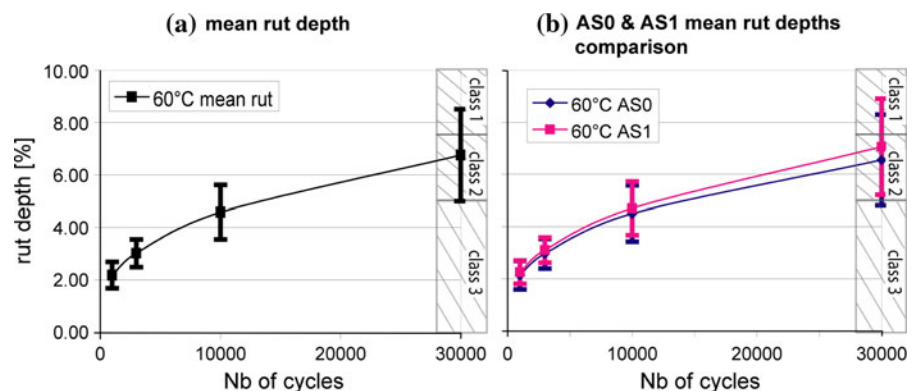
It appears that the anti-sticking procedure has no effect statistically, except for slightly decreasing the scattering between left and right specimens. This is interesting because in the rare cases where sticking is observed, it may stop sticking and allow the test to be performed; and in the cases where sticking is not observed, mean results do not seem to be really affected. Few laboratories have observed sticking, only Lab1 and Lab3. For them, the procedure enables the test to be performed to the end.

Considering that specimens were statistically the same for all the laboratories, it was thought that the origin of the sticking could be related to differences between tyres. This could also have an influence on scattering of results.

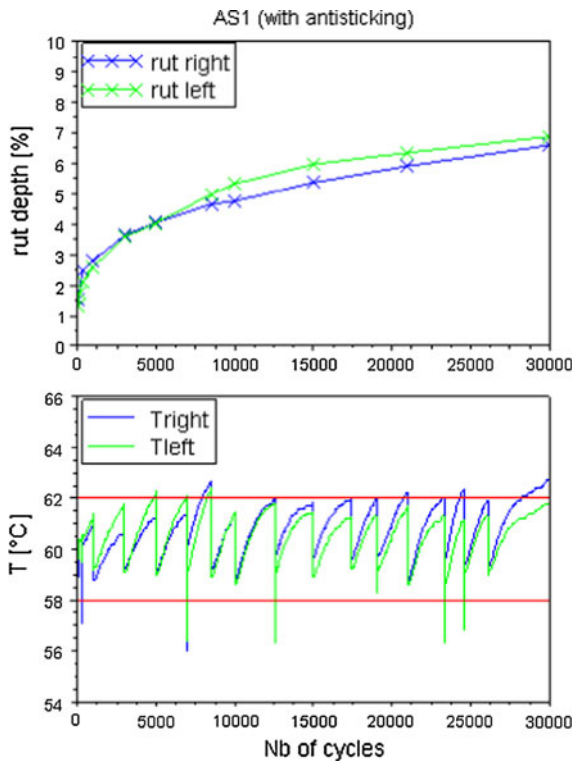
### 3.5 Anti-overheating procedure

This procedure was supposed to be applied to all the tests, at 50 and 60°C. At 60°C, some laboratories have performed these tests while precisely measuring the temperatures inside the specimen, as a function of time through tests. Only these results will be discussed: they reflect the general trend.

**Fig. 13** a Mean rut depth values for all tests performed at 60°C. b Comparison of AS0 and AS1 results at 60°C, in terms of mean values and standard deviations. All tests of Fig. 11 are considered except AS1-lab6-right. Performance class considering French design method are also indicated



Some results of rut depth and temperature as a function of cycles for Lab1, Lab4 and Lab7 are presented in Figs. 14, 15, and 16 respectively.

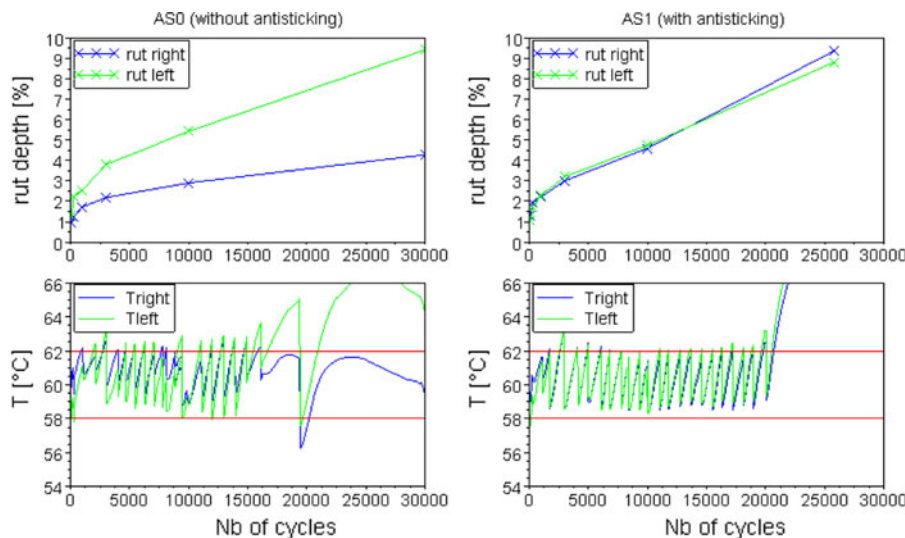


**Fig. 14** Results of lab1 for a AS1 test. Rut depths and temperatures measured inside the samples as a function of the number of cycles

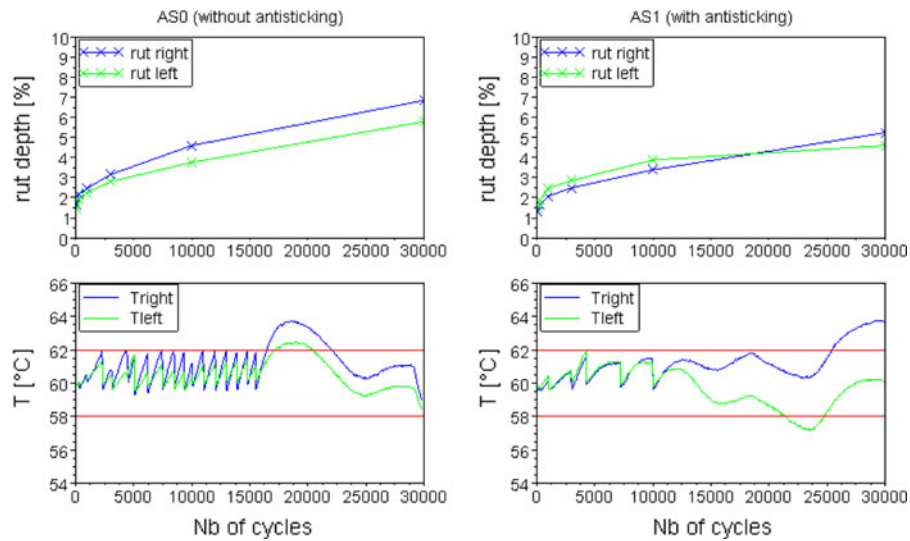
These results first show that none of these three laboratories succeeded in fully following the anti-overheating procedure *through the tests*. Indeed, according to the “temperature” versus “Nb of cycles” curves, each sudden decrease of temperature is related to a stop of the test and opening of the door of the thermal chamber. This stop enables the temperature to decrease before test is restarted. We can observe that all the participants let temperature exceed the critical limit of 62°C at the end of the tests (after approximately 20 stop procedures). To follow totally the procedure was to much of a constraint for the technicians in charge of the tests and would have been very time consuming. As an example, AS0 lab7 was performed over 3 weeks. We can also see that even when the procedure was followed, the limit temperature was sometimes slightly exceeded. Technicians could not stay in front of the apparatus, which can explain late reactions. A possible improvement would be to automate the procedure. However, it can be concluded that the procedure is well respected from the beginning and during the main part of the test.

### 3.6 Correlation between rut and temperature increases

Results, presented in Figs. 14, 15, and 16, tend to show a correlation between rutting and temperature increase. Indeed, if left and right rut depths are compared to left and right temperature evolutions, it

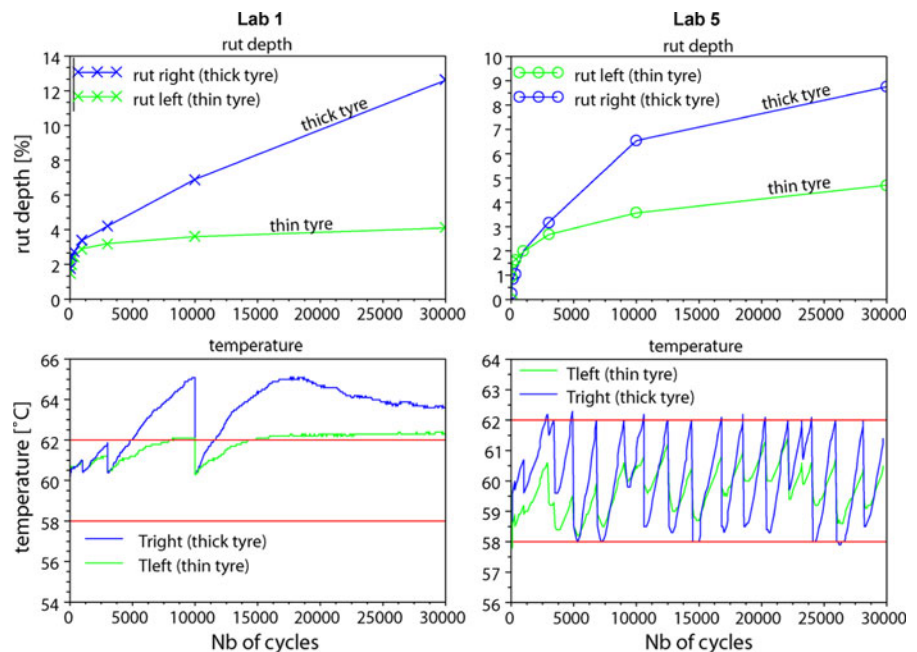


**Fig. 15** Results of lab4. For both an AS0 and an AS1 test, Rut depths and temperatures measured inside the samples as a function of the number of cycles



**Fig. 16** Results of Lab7. For both an AS0 and an AS1 test, Rut depths and temperatures measured inside the samples as a function of the number of cycles

**Fig. 17** FWTT performed on both Lab1 and Lab5 apparatus, equipped with a thick and a thin tyre. Rut depths and temperatures versus number of cycles



can be seen for the presented tests, that equal rut depth curves can be related to identical temperature curves (Figs. 14, 15 (AS1)). For the others, higher rut depths can be correlated to higher temperatures during tests. For example, during the AS0lab4 test (Fig. 15 (AS0)), peaks of temperature are higher and rutting is more significant, as well as for the test AS0lab7 (Fig. 16 (AS0)). At the end of the AS1lab7

test (Fig. 16 (AS1)), between 10,000 and 30,000 cycles, the higher temperature can be correlated to an increase of rut depth. Results presented in Fig. 17 (in the framework of a study of the influence of tyres) seem to confirm this correlation between the level of temperature and the level of rut depth.

This trend between the increase of temperature and increase of rut depth is well known for bituminous

mixtures. It can be explained by the thermo-susceptibility of this material; an increase of temperature during the test leads to a decrease of viscosity and stiffness of material and this then involves more movements of the granular component and more rutting [7].

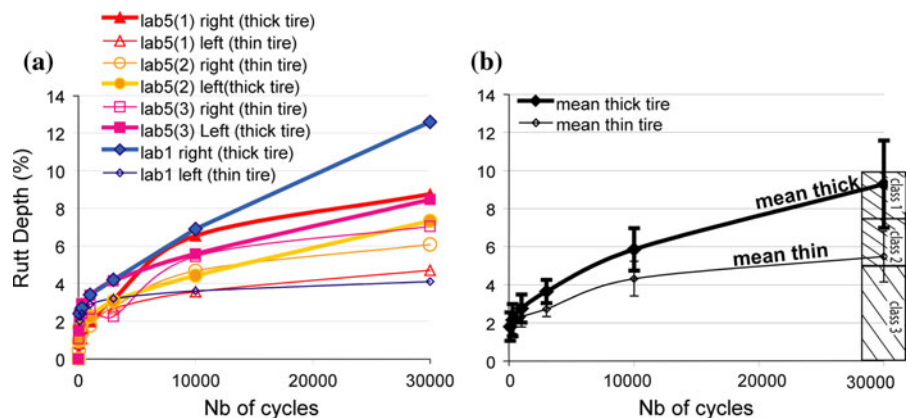
### 3.7 Tyres responsible for scattering?

A difference between tyres has been suggested as a possible cause of the variability of the results. Closed to the end of the campaign, it was found after recheck of experimental conditions that surprisingly, different types of tyres were used among the teams. All the tyres have the same profile and apparently the same dimensions. But a difference was seen in the weight and thickness as explained in the following.

To check this, Lab1 and Lab5 have performed FWT tests, using a “thin tyre” on one side and a “thick tyre” on the other side of the apparatus. Results are presented in Figs. 17 and 18. In Fig. 17, rut depths and temperatures are plotted as a function of the number of cycles. These results are presented separately because they are useful both for this study and also the study on the influence of temperature (see below).

Both rut depth and temperature reach lower levels on the side equipped with the “thin tyre”. Lab 5 has carried out 3 tests in this configuration. Results are summarized in Fig. 18a, where it can be seen that rutting is always more significant when the thick tyre is used. Figure 18b also shows less scattering (in absolute terms) for tests performed with the thin tyre. These results clearly highlight a strong influence of tyre.

**Fig. 18 a** FWTT performed by Lab1 (1 test) and Lab5 (3 tests), equipped with a thick and a thin tyre. **b** Comparison by means values of thin and thick tyres. Performance class considering French design method are also indicated



**Table 6** Tyres mass comparison between Lab 1 and Lab 2

Lab	1	2
Mass (g)	3290	1890
Diameter (mm)	408	435
Print (cm <sup>2</sup> )	70	88



**Fig. 19** Tyres size comparison between Lab 1 and Lab 2

The thick and thin tyres have been analysed in terms of masses, sizes, structures and foot prints. Results are presented in Table 6, Figs. 19, 20 and 21.

This comparison highlights an important difference between the two tyres, leading to different diameters and different footprints for a same inflated pressure (0.6 MPa). The tyre from Lab1 has a thicker structure constituted of six layers and the tyre from lab2 has two layers. Consequently, the tyre from Lab1 is stiffer and shows a smaller footprint. Prints are 70 and 88 cm<sup>2</sup> for the thick and the thin tyre respectively. In addition, even if such a print cannot give the local intensity of the pressure at a given location on the surface, the less coloured parts of the print can be related to low pressure zones, which amplify the level of pressure at the middle of the



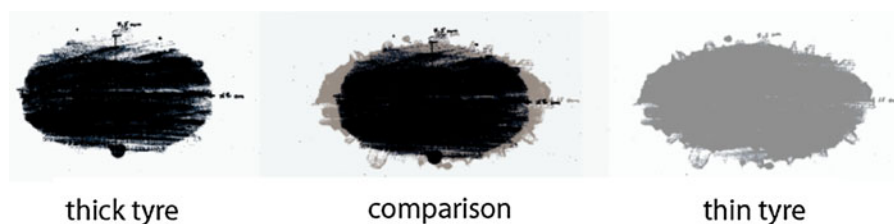
**Fig. 20** Pictures of tyre sections: Lab 1 (*thick tyre on the left side of both pictures*) and Lab 2 (*thin tyre on the right side of both pictures*)

thick tyre (Fig. 21). Thus, the specimen under a thicker tyre is subjected to a more concentrated pressure, which leads to more rutting. This result is quite typical for bituminous mixtures.

Each laboratory has been asked to assess its tyres. It turned out that there were not only thin and thick tyres, but also intermediate. A comparison between the measured masses, the rut depths and the print surfaces has been performed (see Tables 7 and 8). This has not allowed a clear demonstration of a direct correlation between these three results: masses ranking, rut depths ranking and print ranking. It can be concluded that different tyres may lead to different results, but the different results are not only due to differences between tyres.

The European standard EN 12697-22 stipulates (in paragraph 6.1.1.1) the pressure inside the tyre, the dimensions ( $440 \times 8$ ) and the track width ( $80 \pm 5$  mm). In a note of this standard, “the Trelleborg T522 BV Extra or Special 6 ply type” is considered as “suitable for this test”, but as this is only a note, no laboratory is, however, constrained to use this type of tyre. All the laboratories did use a Trelleborg T522 tyre, but it seems that under this unique reference, two types of tyres (2 and 6 ply) are produced. Since the present study demonstrated that this affects the results, users must be aware of that. It is necessary to make the EN 12697-22 more specific on this point. A specification on both print length and width could be added.

**Fig. 21** Tyre footprints and superposition (*thin and thick tyres*)



**Table 7** Mass of tyres according to the laboratory

Lab	1	2	3	4	5	6	7
Mass (g)	3290	1890 or 3200 <sup>a</sup>	2750	3112	3071	2150	3200

<sup>a</sup> The two models can be used by lab02 for rutting tests





## 4 Conclusion

Under the auspices of the RILEM TC-ATB TG3, this experimental programme has been carried out in order to evaluate the capability of the French Wheel Tracking Test to characterise the rutting behaviour of asphalt concrete containing bitumen highly modified with polymer. A peculiar plastomer of EVA type has been chosen to modify the bitumen. The Round Robin Test performed has highlighted, for such test on AC-PmB, a reproducibility of results comparable to those obtained in other Round Robin Tests on classical materials [8, 15].

Two specific procedures have been assessed: an anti-overheating and an anti-sticking procedure. From a practical viewpoint, it was observed in previous studies that the anti-sticking procedure could be helpful to avoid sticking problems between the tyre and the sample. Our analysis has shown that such a procedure has statistically no influence on the results of the performed campaign. Only a slight positive effect which consists in a trend to decrease the scattering between the left and right side results on a given apparatus was observed. Our conclusion is that it is a free choice to use this anti-sticking procedure. It could be necessary if strong sticking phenomenon appears.

An anti-overheating procedure has also been developed to be followed by all the laboratories during this RRT. Such procedure prevents the tests from being partially running outside of the standard temperature. Unfortunately, in some cases, like tests on our AC-PmB, respecting this procedure strictly is quite difficult, as it can increase the test duration by

**Table 8** Prints ranked from the smallest to the biggest (same scale)

Laboratories	Lab1	Lab5	Lab2	Lab3
Print				
Print surface (cm <sup>2</sup> )	70	85	88	112
Mass (g)	3290	3071	1890	2750
Mean rut depth at 60°C and 30,000 cycles (%)	6.73	7.06	5.18	6.7

more than 2 weeks and necessitates constants actions from a technician. Therefore, this apparatus could be improved by automating the stop and start function to turn off when the maximum temperature is exceeded and then restart when the minimal requested temperature is reached. The thermal regulation system could also be improved by adding a cooling source.

It has also been revealed that a large scattering was caused by difference between the tyres used on the different apparatus. Despite a common main reference number, tyres can have different structures and thicknesses. Then, it is important to control structure of each tyre, as well as its print in terms of length and width (and not only the width as mentioned in the standard). In addition, problems of sticking could in some cases probably be solved while using tyre as advised by standard.

The sample preparation can also be the cause of the scattering. During this programme some of the manufactured concrete slabs were over-compacted, which creates “outlayers” that were not considered for the analysis. Finally, studying the rutting problem on this type of apparatus needs great care, due to the strong heterogeneity, the complexity of the loading, and the poorly controlled boundary conditions.

Then, if the previous aspects (stricter temperature control, tyre characteristics, sticking prevention and specimen preparation) are respected, reproducibility could be strongly improved. This remark is true for any kind of asphalt concrete made with pure binders or modified binders.

**Acknowledgments** We would like to thank all the laboratories which took part in this Round Robin Test: BRRC (Belgium), EIFFAGE Travaux Publics (France), ENTPE (France), IBDIM (Poland), LCPC (France), LUCREB-ÉTS (Canada), NTEC (United Kingdom), TOTAL (France).

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