

INDIRECT TENSILE FATIGUE TEST FOR ASPHALT MIXES COMMONLY USED IN FRANCE

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ABSTRACT

Adapting the measurement of fatigue via indirect tensile test, according EN 12697-24 annex E, to asphalt mixes commonly used on French road networks. International round robin tests on high modulus asphalt concrete called COMPOMODULE®, designed by SCREG. This method provides a quick decision-making tool in asphalt mixes design.

Adaptation de la méthode de détermination de la tenue en fatigue par traction indirecte suivant la norme EN 12697-24 annexe E, appliqué à la formulation d'enrobés bitumineux usuellement mis en œuvre sur le réseau français. Essais croisés internationaux sur des enrobés à haut Module de type COMPOMODULE® – SCREG – Débouchés de cette méthode pour une aide rapide à la décision de choix de formulation.

Keywords: Indirect tensile test, Fatigue, high modulus asphalt concrete

INTRODUCTION

For over two years, laboratories throughout the network of Screg companies have been working to adapt the indirect tensile fatigue test to determine fatigue behavior during the study and design of special asphalt mixes. The test is performed in compliance with instructions included in appendix E of European standard EN 12697-24. The operations sequence, initially developed at the VTI laboratory in Sweden, was adopted up by the EU Committee for Standardization as one of the possible methods used to determine asphalt mix fatigue.

The method consists in characterizing asphalt mix fatigue behavior under repeated loads with constant stress using indirect tensile (ITT). Diametral compression force is applied to a cylindrical specimen followed by rest time. The resulting horizontal deformation is measured to calculate tensile deformation in the center of the specimen.

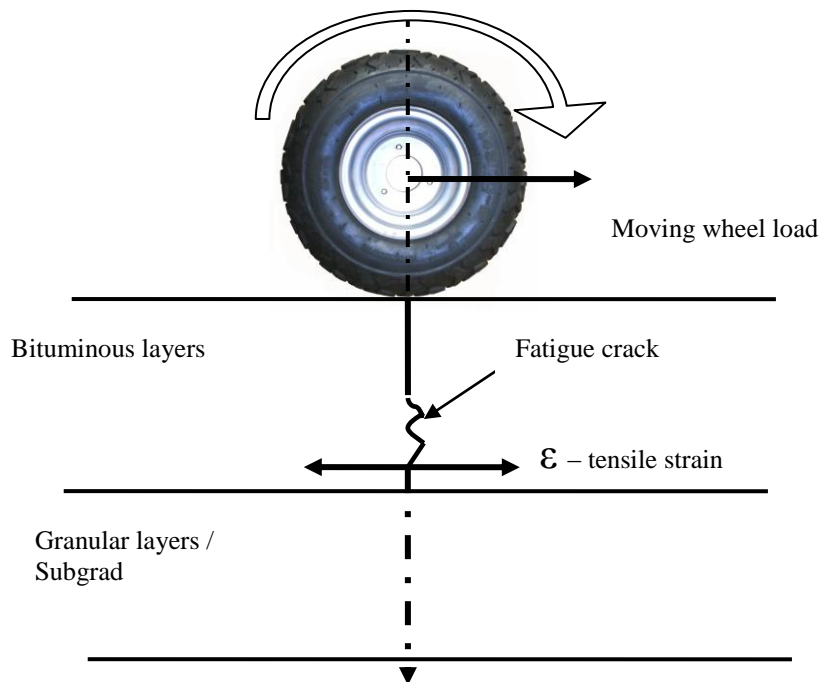


Figure 1: Tensile strain in asphalt layer caused by moving wheel

A roadway receives repeated loadings due to the tires of vehicles as they pass along. The indirect tensile fatigue test, is exposed to repeated compressive loads (constant frequency); this loadings develop a relatively uniform tensile strain along with the horizontal diametral plan; the generated deformation signal is comparable to the transversal strain signal form measured during the vehicle passage. (cf. Figure 1)

The fatigue tests most commonly used in France – appendix A of standard EN 12697-24 – is very time-consuming, and requires costly equipment: plate compactor, digital saw table, template analyzer, and special fatigue machines for trapezoidal specimens.

We are truly convinced that a method like the one used in this indirect tensile test provides rapid, sufficiently accurate for routine use and reliable results in the framework of an asphalt mix design study or for verification in situ of materials after construction.

The method provides added value from a technical viewpoint, and is an efficient complement to official fatigue tests required in ‘level 4’ studies (Duriez, Gyrotory Shear Press, rutting, stiffness modulus, fatigue)

1- SCREG EQUIPMENT



Photo 1: Cooper NU 14 press, with drive and data system

Every laboratory in the Screg network is now equipped with an electro-pneumatic press initially acquired for stiffness modulus tests. After reading “*Validation of Indirect Tensile Test for Fatigue Testing of Bituminous Mixes* – VTI notat 8A -1998 by Safwat F. Said, technical managers at Screg quickly realized the opportunities that these machines could provide in terms of assessing asphalt mix service life and fatigue



Photo 2: Gyratory Shear Press used to manufacture specimens with 100mm diameter and a predefined air void content in % (geometrical).

2- HOW THE TESTS ARE PERFORMED (SPECIMENS/SELECTION)

As mentioned above, fatigue tests using indirect tensile differ from other fatigue tests in that they are less expensive (equipment and technician man-hours) and easier to perform. The test is based on simple principles, meaning that it can be performed in any ordinary laboratory. However, care must be taken as far as metrology, temperature, force measurement, deformation, loading time, data collection, and specimen quality are concerned.

When performing this type of test in a laboratory, specimens are simple and easy to manufacture using the gyratory shear press in 100 mm diameter and with thicknesses that vary as a function of the mix's stiffness and maximum aggregate size. 18 specimens are recommended for fatigue test of a mix, with tight controls over the geometric and hydrostatic density. Verify that their compaction ratio varies no more than 1% compared to the average of all specimens and discard non-compliant specimens.

The test can also be performed by manufacturing slabs of asphalt mix then boring specimen. These specimens must also be verified, sorted and all non-compliant specimens removed. The same care must be taken when cores are bored in situ.

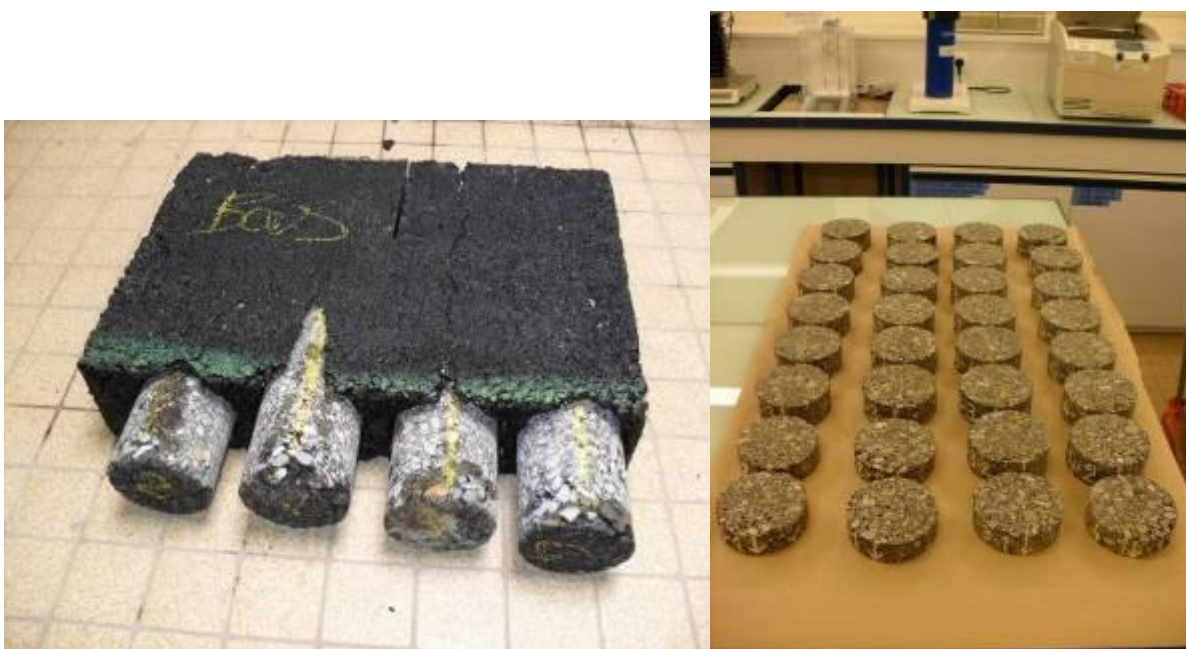


Photo 3: Slab of asphalt mix with bore-cores and specimens ready for testing.

When the asphalt mix slab is manufactured with a lab compactor (photo 3), we bored the cores for fatigue and modulus test perpendicular to the axis of compaction for two reasons:

- Compaction ratio is highest in the middle of the slab, boring the cores perpendicularly means that we get better air void distribution, which in turn leads to more homogeneous distribution of voids in the specimen;
- The fatigue test is performed by applying force on the axis of compaction, meaning that the test will be as close to reality as possible.

Before the fatigue test as such is actually launched, the specimens must cure for at least one week.

We also perform elastic modulus tests on the specimens 24 hours prior to the fatigue tests. This helps us make an even more rigorous selection of the specimens, by removing any piece that shows a modulus which is too far off the mean values, thus ensuring an average of 10% variation in the specimens selected. This test is very fast and makes it possible to verify homogeneity. Generally speaking, out of the 18 initial specimens, 4 are removed.

After selection of homogeneous specimens the test is performed in compliance with the standards, in addition to one extra detail: the deformation bars must be glued to the diametral horizontal plane, and the specimen must be centered to ensure that the force applied is perfectly perpendicular to the axis of horizontal deformation. The bar that is used to apply the force is articulated (cf. Photo 4) in order to ensure the best possible spread of vertical stress.

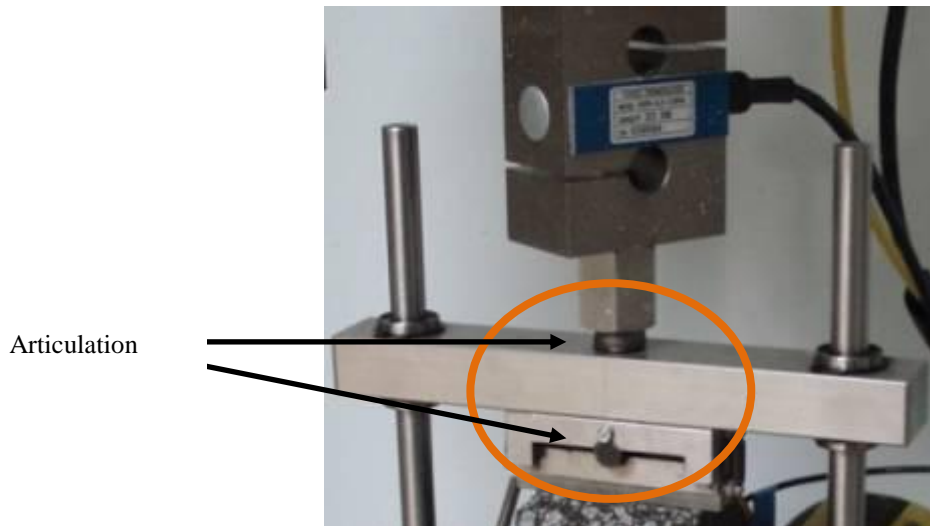


Photo 4: Load arm articulation

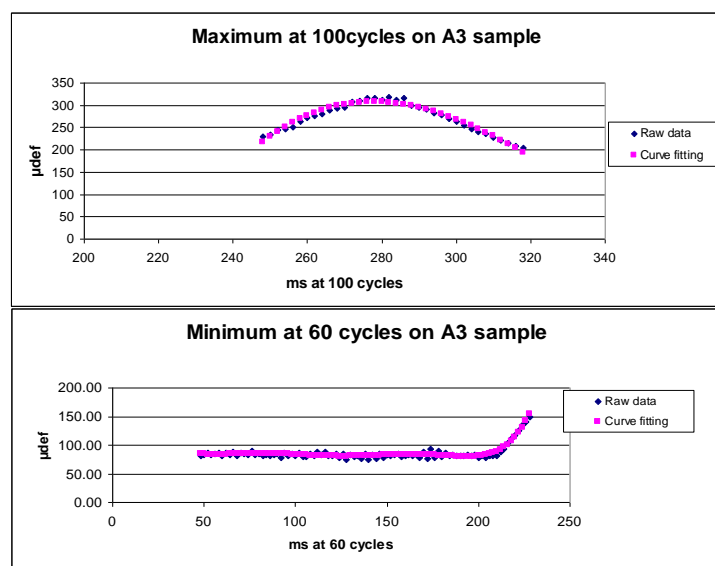
Analyzing test results:

Data is collected with a frequency of 500 Hz, which provides force, time and deformation every 2 milliseconds. The initial strain shall be calculated from the total horizontal deformation after preconditioning. The initial strain is calculated after the envelope of the deformation has been stabilized and the repeated deformation has become stable, which normally occurs before 60 load applications. The initial strain value is calculated from the difference between the total (maximum) horizontal deformations at 100th application (practically average of 5 applications, 100 -105 cycles) and the average of the minimum horizontal deformations at 60th applications (practically average of 5 applications from 60 to 64).

It is easy to analyze the curves between 60 and 65 cycles, using a polynomial equation to determine the minimum value of the curves and calculate the average. Similar curve fitting is done for signal between 100 and 105 cycles for determination of the average of maximum value. Initial deformation (ϵ_0) is calculated as the difference between the two values.

In the graphs hereunder (Figure 2), we have included part of the graphic analysis of the test results at 60 and 100 cycles.

$\mu\epsilon_0 =$	227.62
TD 100	307.47
TD 101	308.99
TD 102	311.34
TD 103	308.65
TD 104	310.71
TD Average	309.43
MD 60	79.74
MD 61	82.54
MD 62	80.75
MD 63	82.58
MD 64	83.43
MD Average	81.81



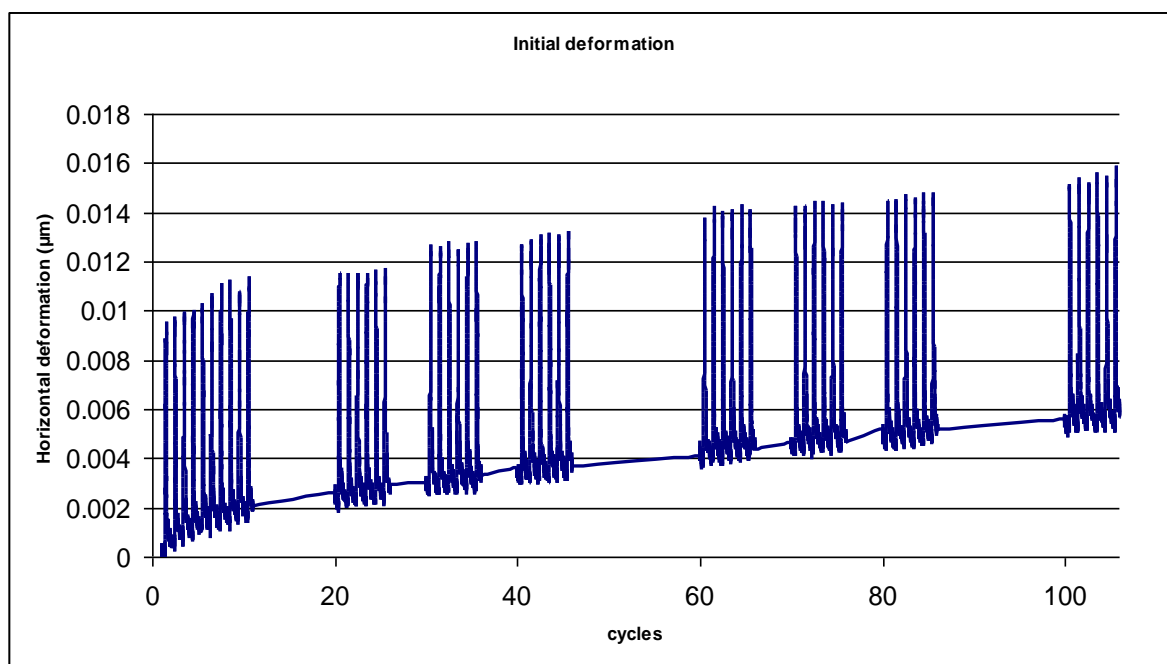


Figure 2: Acquisition of data concerning “μm deformation /cycles0 to 105” on test performed on specimen A3: all values are not presented to improve readability

Therefore:

$$\Delta H_0 = TD_{100 \text{ av}} - MD_{60 \text{ av}}$$

with:

TD 100 av is the average of total deformation in cycles 100 to 104

MD 60 av is the average of minimal deformation in cycles 60 à 64

Rest time and cracking

Another major issue involves the fact that this method is the only one that calls for ‘rest time’ amounting to a full cycle. Other fatigue tests force the specimen to come back to its initial position, whereas the indirect tensile test allows the specimen to recover from deformation during a rest time at the end of the load cycles. (cf. Figure 3).

Traffic load, consists of short and quickly load pulses, followed by rest periods; therefore this test is a good simulation of the in-situ conditions and its resulting transversal horizontal strains is comparable to that created by a load rolling on a roadway. However, do rest times (0.4 seconds) actually allow specimens made with conventional French hot mixes (0/14 class 4) or special high modulus mixes designed by Screg to completely recuperate from deformation?

The following graphs show that horizontal deformation recovers its initial state after a period of stabilization, as long as we remain in the range of preponderant elastic deformation. Therefore, we validate a release time of 0.4 seconds for all of our tests, regardless of the load, temperature or mix stiffness.

On the other hand, we can see towards the end of the test that plastic deformation increases sharply. This indicates that the linear phase is completed and that we have reached the ‘fracture’ phase, as illustrated in the graph (e) Figure 3.

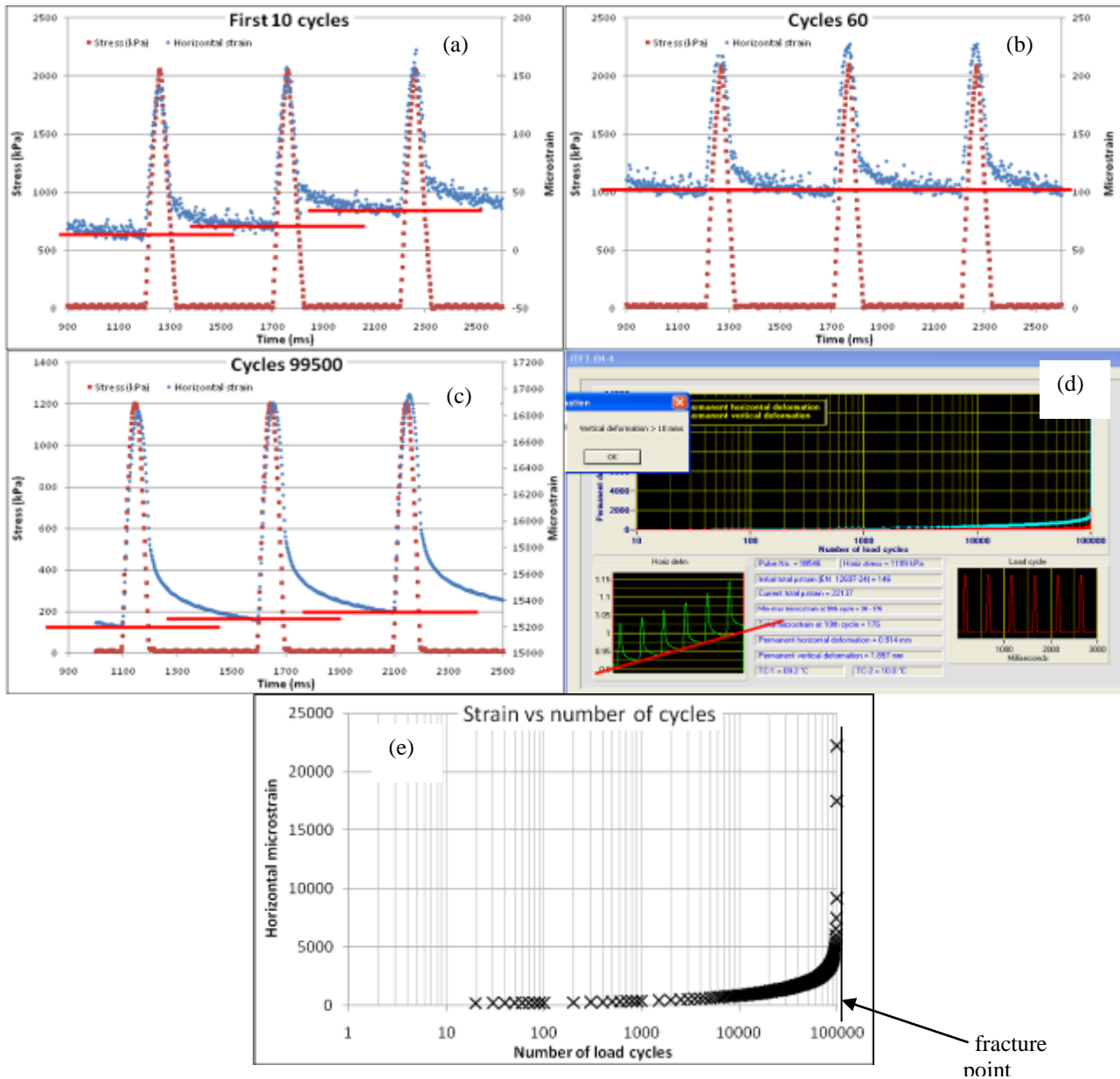


Figure 3: Recuperating deformation during rest time – high modulus2 (FT 11-35, specimen 4-2, 1200kPa)

Fatigue criteria in a given hot mix are determined after analyzing findings from tests performed on specimens. A regression ratio using the least squares method is applied to logarithm data for total initial deformation (ϵ_0) as an independent variable and to logarithm data of service life before fracturing (N_f) as a dependent variable according to the following equation:

$$\log N_f = k + n \log \epsilon_0$$

with:

- N_f the number of loads applied before fracturing;
- ϵ_0 total initial deformation in tensile in center of specimen;
- k and n are constants of asphalt mix tested

Fracture criteria

According to existing methodologies, different criteria define fracturing in the specimen. When using the method discussed herein, it is simple, efficient and repeatable to use a single definition: “the test is completed when the specimen has fractured”.

On the one hand, this is a logical decision because the other definitions are arbitrary or do not take into account the fact that we are using total deformation. In addition, waiting for full fracture does not make the test much longer, because it is not time consuming in the first place.



Photo 5 : fractured specimen (FT 10-07, B12)

With ΔH_0 we can easily calculate total initial horizontal strain in the center of the specimen (in microstrain) using the following equation:

$$\varepsilon_0 = \left(\frac{2 \cdot \Delta H}{\Omega} \right) \times \left[\frac{1 + 3\nu}{4 + \pi \times \nu - \pi} \right] \cdot 10^6$$

with Ω as the diameter in mm of the specimen being tested.

How selective is the method?

To assess how selective the method is, the SCREG Ile de France Normandie laboratory performed a series of tests on mixes with different degrees of stiffness.

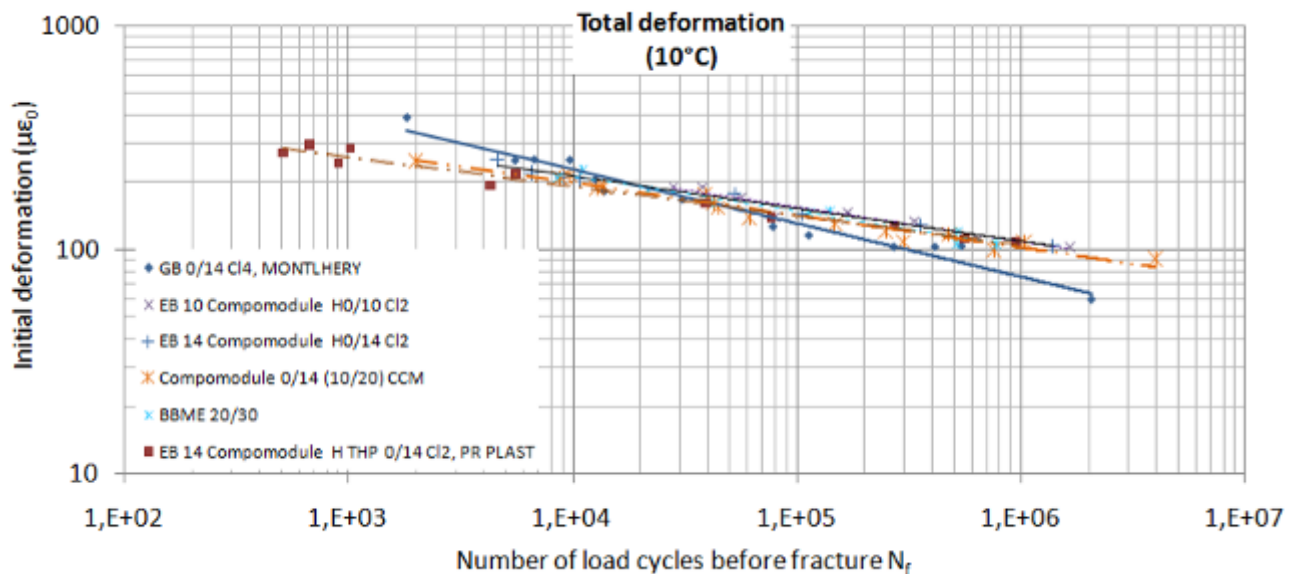


Figure 4: Selectivity of ITFT

Figure 4 shows that, for the same laboratory, the constants in fatigue laws that come from test findings are different, depending on the type of mix used (tests performed on mixes ranging in modulus from 11000 to 22000MPa).

3- ROUND ROBIN TESTS

3.1- first series of round robin tests with French road base asphalt concrete (GB type 4 0/14)

As early as 2008, Screg's technical departments set up a series of round robin tests with VTI involving a commonly used French hot mix: GB 0/14 class 4 with 20% RAP, and modulus at 15°C of 11000 MPa. Three labs participated: Screg Ile de France Normandie and Screg Est for France and VTI – Linköping for Sweden.

The initial goal was to acquire the expertise we needed and to ensure feasibility on hot mixes that are often used on French roads.

- The specimens were made at the Screg Ile de France Normandie laboratory, using a gyratory shear press, a tried and true mix design and were assessed with a 2 point bending fatigue test. The specimens were sent out to the three labs, taking great care to make sure the specimens were as homogenous as possible in terms of compaction ratio, dimension, and stiffness modulus. Threshold values for rejection were determined to ensure that all the labs were working on representative specimens of the same mix design. With this data, we were able to find encouraging reliability values (repeatability and reproducibility) that validated this first series of tests for use within the Screg network to help develop special mixes (cf. figure 5)

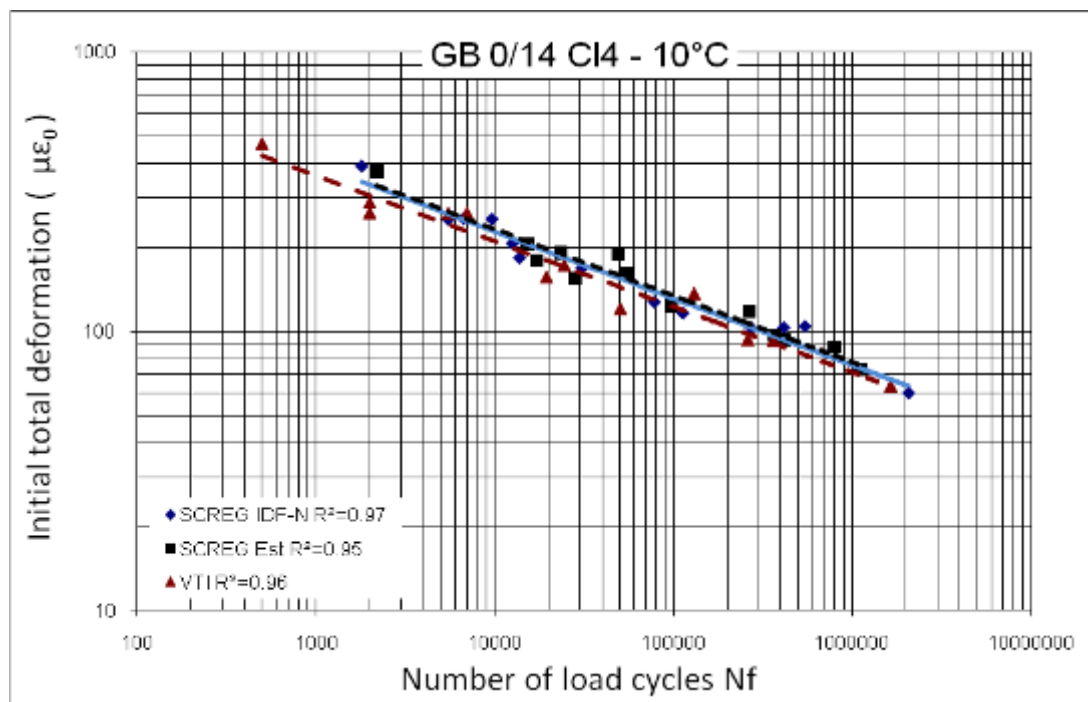


Figure 5: GB 0/14 c14 (binder content 4.5%; Modulus 12900 MPa) – Estimate of fatigue by indirect tensile

SCREG Ile de France Normandie				SCREG Est				VTI			
$\mu\epsilon$	Nf	n	-4.04	$\mu\epsilon$	Nf	n	-4	$\mu\epsilon$	Nf	n	-4.09
73.7	10^6	10^k	$3.51E+13$	75.3	10^6	10^k	$3.17E+13$	68.9	10^6	10^k	$3.31E+13$
		R^2	0.97			R^2	0.95			R^2	0.96

3.2 Round robin tests currently underway

We are currently performing reliability tests on the method with several European laboratories and two specific mixes: one with 70/100 bitumen and the other with 10/20 bitumen. The mixes were manufactured by VTI in Sweden for the first, and at Screg IDFN Montlhéry for the second.

The first was designed in Sweden for road base courses with a modulus of nearly 8000 MPa at 10°C and a 3% air void content;

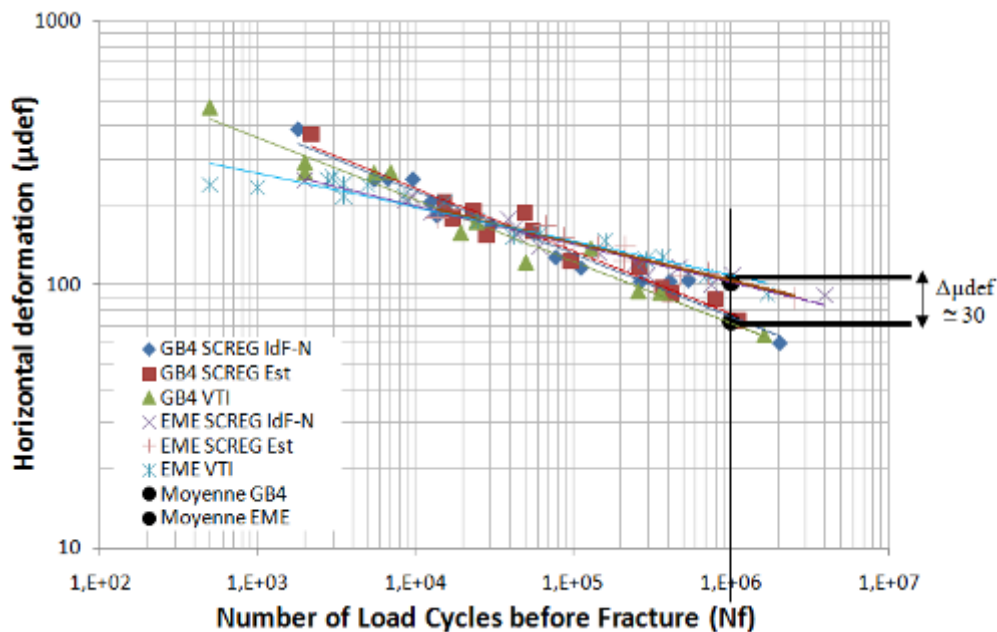
The second, designed by Screg, is a high modulus **Compomodule® H** type mix with 23000MPa at 15°C and a 3% air void content.

Statistical analysis, repeatability and reproducibility of the 2nd series of round robin tests are covered in another paper presented at the EAPA by Safwat SAID from VTI.

In Figure 6, we gathered results from tests performed at SCREG Monthléry, SCREG Nancy and VTI, the first round robin tests on the GB 0/14 c14 and the round robin test performed during the last phase, on **Compomodule®**.



Photo 6: samples of Compomodule® for round robin tests



ITFT	SCREG Ile de France Normandie			VTI			SCREG Est		
	n	R ²	ε ₆	n	R ²	ε ₆	n	R ²	ε ₆
GB ₄	-4.04	0.97	73.7	-4.09	0.96	68.9	-4.00	0.95	75.3
EME2	-6.65	0.96	101	-6.56	0.97	103	-6.50	0.94	102

Figure 6: Round Robin test results at Monthléry/Nancy/VTI – High modulus EME2 and road base asphalt concrete GB4

The test results show that the variation at 10⁶ cycles is roughly 30μstrain, which corresponds to specification in France.

In addition, the findings show that the test is selective. It can also be used to highlight the different performance levels of mix designs, and it preserves conventional variations.

4- TESTS ON COMPOMODULE®:

Compomodule® is a range of high modulus asphalt mixes designed by Screg, combining bitumen binders and additive agents that provide improved stiffness compared to conventional road base asphalt concretes.

The indirect tensile fatigue test on **Compomodule®** makes it possible to compare endurance of various mix designs. In fact, several tests done in the Screg Monthl  ry and Nancy labs on specific **Compomodule®** mixes show that curves obtained with ITFT are comparable to 2 point bending tests.

Material	Temperature	n ITFT	R ²	n Aliz��e	2 point bending
Compomodule P (11-13)	10��C	-7.44	0.97	-5	ND
Compomodule H 0/14 (09-37)	10��C	-6.76	0.98	-5	-6.70
Compomodule H 0/10 (09-10)	10��C	-6.00	0.92	-5	-6.15

Chart 1: Comparing curves between ITFT, standard and 2 point bending test

5-ADAPTATING PNEUMATIC MACHINE FOR FATIGUE TESTING

Air – compressor and dryer

The test made it possible to study extremely stiff mixes, if there is enough air flow to create sufficient force, which corresponds to short service life spans. Moreover, the compressor must also be able to supply constant, uninterrupted low pressure flow for long service life tests.

On the example in Figure 7 – (same specimen as figure 2) – we can see the initial 228   strain for stress totaling 1700 kPa (13 kN). The shear press, force sensor, pilot can withstand the pressure. However, the air flow is enormous, and it requires dry, constant air flow. An air dryer must be mounted upstream from the shear press to prevent water from penetrating in the apparatus. Constant force is also very important for the test’s validity. If the air flow varies, stress will vary, which means that different service lives will be expressed and they will not be highly repeatable.

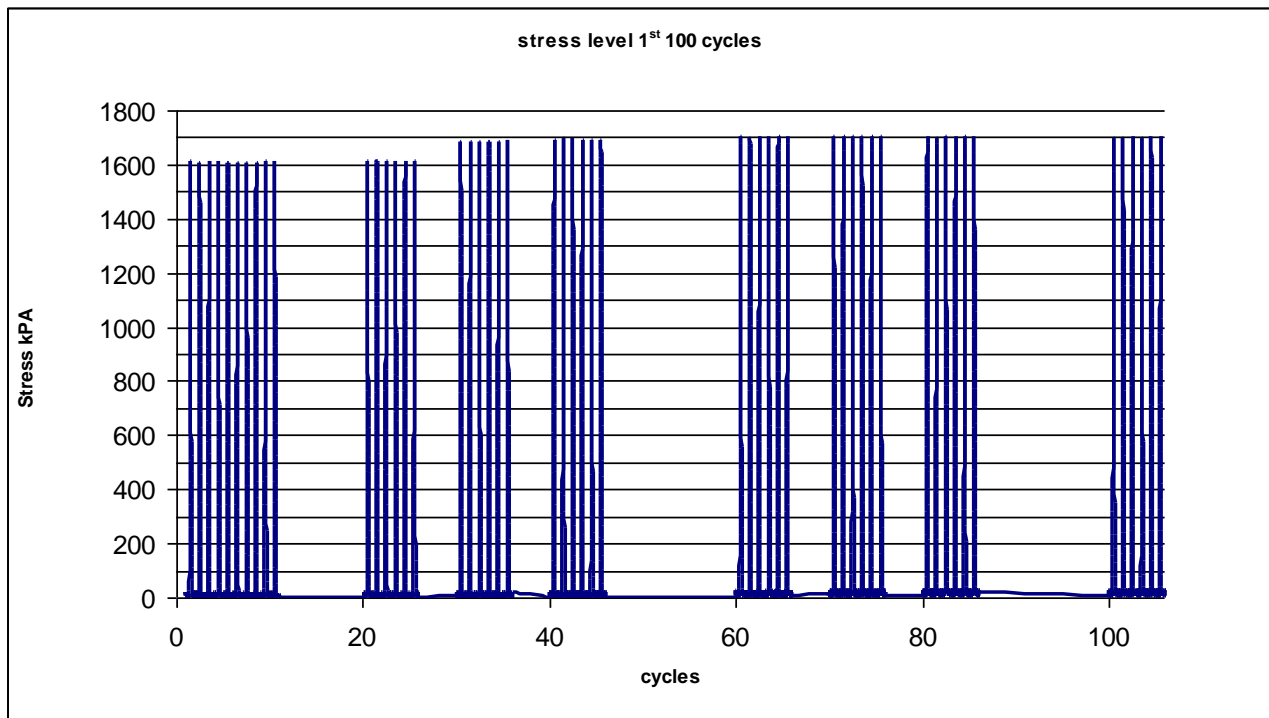


Figure 7: Acquisition of data “Stress kPa /0 to 105 cycles” on test; all values acquired are not presented to improve readability.

It is important not to neglect the importance of having dry air. With the release phase on each cycle, it is very cold, and if the air is too moist, it could freeze, which would cause extensive damage.

We found repeatable results by installing a compressor and dryer able to supply dry air at constant pressure at 10 Bars at the entry of the shear press.



Photo 7 : Compressor - Dryer

Press

Laboratories at Screg use a NU-14 by COOPER Technology. The reliability of the apparatus and the pilot drive are periodically verified to ensure proper metrology by a certified laboratory (national and international standards in force, deformation, time and temperature).

Deformation sensors

The deformation sensors must be set at $< 1 \mu\text{m}$ accuracy; with a range of measurement able to detect deformation to fracture (2mm is sufficient for most mixes commonly used in France).

Even if most modern systems are high resolution (display system), precision and in particular uncertainty of measurement are not as easy to ensure. These depend on the quality of the sensors (in particular linearity and repeatability) and calibration. To satisfy measurement requirements, it is preferable to have sensors with an uncertainty of measurement of no more than $1 \mu\text{m}$. LVDT can comply, with proper calibration and polynomial setting.



Photo 8: LVDT on specimen

Deformation bars, bonding

The deformation bars that encircle the specimen's radius of curvature **MUST BE BONDED TO THE SPECIMEN** (cyanoacrylate glue) in order to avoid all undesirable measurements. Springs may be used to install the bars on the specimen but must not be used to hold the specimen during the trial.



Photo 9: Gluing rack designed by VTI, a requisite for proper bonding on diametral plane.

Acquiring data

Loading and unloading occurs in 500 ms, with a load time of 100 ms and an unload time + release time of 400 ms. Hence, measurements must be taken at least every 300 Hz (3.3. ms). The NU 14 data acquisition system acquires data every 500 Hz, which means that all data is measured every 2 ms.

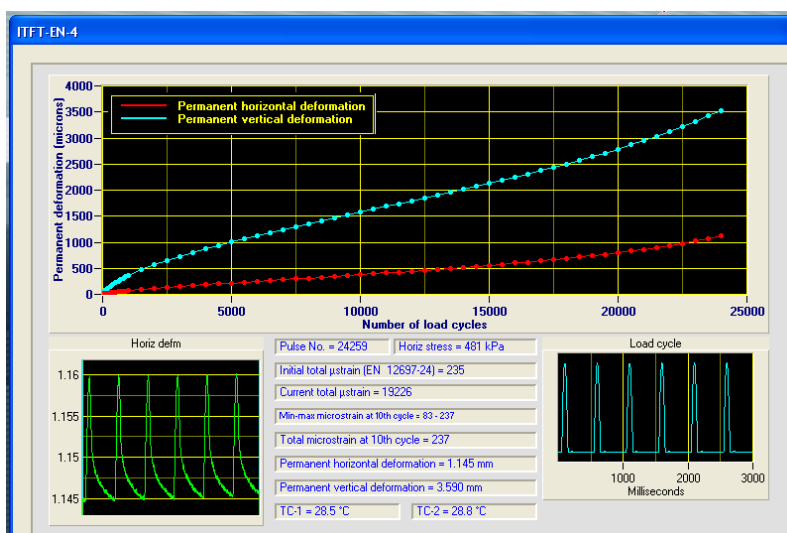


Photo 10: Software in measurement mode (test is underway, screen print)

Climate controlled enclosure

The press must be placed in a climate controlled enclosure, with precision and homogeneity of $\leq 1^{\circ}\text{C}$. The tests begin once the temperature at the core of the specimen has been stabilized. In the SCREG Ile de France Normandie

laboratory, a double 'barrier' was built in translucent plastic to minimize air flow exchange when the door is opened. This system helped speed up the temperature stabilization process by 20 minutes (at 10°C).

The system also works well during elastic modulus tests when the door is opened more frequently.



Photo 11: Plastic 'barrier', door open (double glazed glass)

6- INTERPRETATING RESULTS:

- It is possible to validate a new mix design by comparing results with other tested mix designs: Because the test is selective, if, for a given mix, we have constant **k** (y intercept), and **n** (slope) of the same value as those obtained on identical mix designs, it is more than likely the mix will be compliant in terms of fatigue, which supposes of course that a data base exists.
- Obtaining threshold values by comparing with other fatigue test methods should be possible. As of today, we only know of a series of tests performed in parallel with the 2 point bending test. We can note however that the **Compomodule**[®] - or EME cl2 high modulus mix-, if the value is $\epsilon_6 > 100\mu\text{strain}$, and the slope ≥ 5 , we can ensure compliance of the product with specifications in France based on the 2 point bending test.
- For the same service life, μstrain are lower during the ITFT, compared to the 2 point bending test. We can imagine being in a position to analyze compliance taking this characteristics into account, and using for example $[\epsilon_6 \text{ (standard specifications)} = \epsilon_i \text{ ITFT}]$. This also supposes that a data base exists, to be able to undertake a wide-sweeping study of all possibilities. This path is nonetheless very promising and has already provided convincing results with $i = (2.10^5)$ cycles.

No. of study	material	E*	Cycles	ε	ε_6 standard
08-66	GB 4 GB 0/14 C14	12896	10000	230	100
			200000	110	
			1000000	74	
09-10	EME EB 10 road base 10/20 Compo. H 0/10 C12	14094	10000	229	130
			200000	139	
			1000000	106	
09-37	EME EB 14 road base 10/20 Compo. H 0/14 C12	15687	10000	214	130
			200000	137	
			1000000	108	
09-46	EME Compo. 0/14 (0/10) THP CCM	22068	10000	201	130
			200000	128	
			1000000	101	
10-07 A	BBME Compo. HMA 20/30 Denmark	14660	10000	216	100
			200000	132	
			1000000	101	
10-07 B	Compolastic ABB Colflex Denmark	9902	10000	261	100
			200000	136	
			1000000	96	
11-13	EME Compo. H THP 0/14 C12, PR PLAST	18678	10000	192	130
			200000	128	
			1000000	103	
11-35	EME Core taken from slab	15000	10000	253	130
			200000	138	
			1000000	100	

Chart 2 : microstrain at $2 \cdot 10^5$ cycles by ITFT vs ε_6 in 2 point bending test

Conclusion:

The Screg Ile de France Normandie and Screg Est laboratories have reliable equipment and the requisite expertise to perform tests that can be used during the design phase to select asphalt mixes depending on their modulus and indirect tensile fatigue.

These tests are reliable, repeatable and quick.

However, there is still much to do in order to create a data base including other types of asphalt mix. ITFT is an alternative test to be used as a 'filter' before official tests or as a control test on specimens taken in situ. This should enable laboratories in the field to improve their selectivity and reactivity on job sites.

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