Development and Validation of the First Brazilian French-Based Asphalt Mix Complex Modulus and Fatigue Test Apparatus

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ABSTRACT

The main aim of this paper is to present the development and validation procedures of the first brazilian french-based asphalt mix complex modulus and fatigue test apparatus, so-called FADECOM. Magnetic sensitive Hall Effect non-contact captors determine amplitude displacement, while loading cells capture force amplitude by a diaphragm system. Independent cooling and heating chambers assure a precise temperature control comprising a range from -30ºC to above 100ºC with an accuracy of 0.1ºC. A frequency inverter controls the emission of pulses usually set from 1Hz to 30Hz. For validating the apparatus, a scientific cooperation agreement was dealt with French Institute of Transportation Sciences and Technologies, Development and Road Network (IFSTTAR), in which specimen samples were tested in both UFSC and IFSTTAR laboratories. The crossed-results obtained indicate an excellent performance and accuracy of FADECOM apparatus, presenting variations around just 3 microstrains in determining fatigue strains at 10^6 cycles (ε_6) and less than 10% related to the complex stiffness modulus.

Keywords: apparatus, development, validation, complex modulus, fatigue.

1. INTRODUCTION

Understanding rheological-mechanical properties of asphalt mixes at different temperatures and loading frequencies is essential, due to influence they exert directly on the viscoelastic linear behavior of these materials [1-4].

The constant need of formulating asphalt mixes able to support the growing, continuous and intense loading axle levels of the traffic fleet worldwide, have been leading to research the effect of high consistent asphalt binders in increasing the stiffness dynamic (or complex) modulus and resistance to fatigue, which is the main phenomenon responsible for the rupture of pavement structures in the field [5-6].

French methodology was chosen to be a reference, due to present a scientific, officially published and proven close field-laboratory rate [7-9], giving strong credibility to the results obtained.

Considering the above-mentioned principles, the first french-based dynamic stiffness modulus and fatigue test apparatus, so-called FADECOM, has been conceived by the Pavement Research and Development Group (GDPPav), pertained to Federal University of Santa Catarina, Campus UFSC/Joinville, endeavoring for more than a decade in continuous researches on physical and mathematical models, as well as on numerical simulations.

Among particular and notable characteristics of the apparatus are its easy portability, despite have a robust and stable stainless steel framework, the capability to carry out complex stiffness modulus and/or fatigue tests with four trapezoidal specimens simultaneously, in continuous mode with displacement amplitude control and generation of sinusoidal loading and displacement signs.

Furthermore, it consists in the first scientific initiative outside France capable to propose a project capable to carry out dynamic (complex) stiffness modulus and fatigue tests in the same apparatus, using trapezoidal specimens tested in continuous mode and with displacement amplitude control, with possibility to perform both mentioned tests under environmental conditioning situations, i.e., in wet and dry states.

2. TECHNICAL CHARATERISTICS OF THE APPARATUS

FADECOM apparatus has a solid stainless steel base, which supports a climatic chamber made of polyurethane. The temperature inside this chamber is adjusted by an automatic digital controller that commands two distinct climatic systems: one for heating and another for freezing. Hence, when one of these systems is being adjusted for operation, the other is deactivated automatically, thus guaranteeing the desired temperature for the tests.

With this automatic digital controller commanding the two climatic systems, it is possible to carry out the tests with temperatures ranging from -30ºC to higher than 100ºC. The temperature value during the tests is supplied by 9 thermocouples placed at different points on the chamber (4 close to the specimens) with an accuracy of 0.1ºC.

A frequency inverter is responsible for adjusting the frequency of the tests, which commands a 6-pole induction motor connected to two eccentric axles. The rotational movement of the eccentric axles generates a force that is transmitted gradually to a set of interlocking pieces until reaching the oscillator rods connected to the specimens (Figure 1).

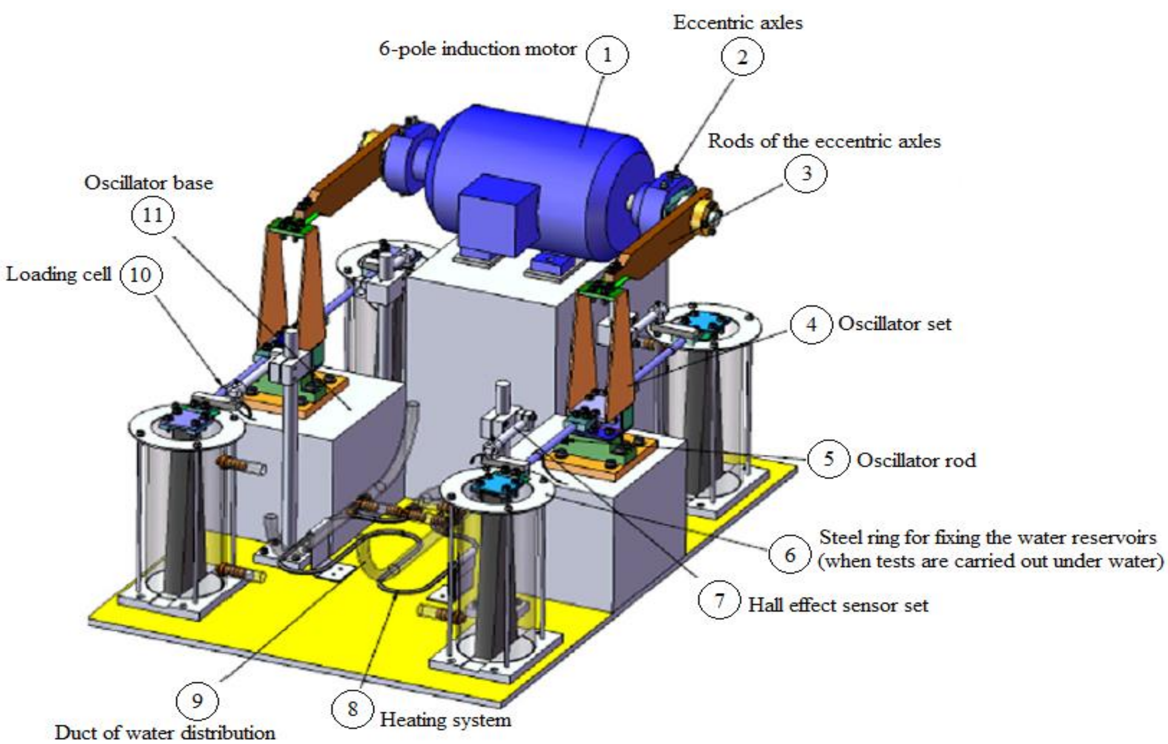

FIGURE 1 Set of Pieces Involved in the Test Procedures

The force transmitted gradually to the oscillator rods applies a back and forth displacement in the top part of the specimens, which generates a sinusoidal loading signal, i.e., alternating flexion effort. The loading and displacement signals are captured simultaneously by loading cells and by the Hall effect sensors, respectively.

A data acquisition system captures the electrical pulses sent by the loading cells and by the Hall effect sensors with a sample frequency of 640 Hz. A computerized terminal programmed in a platform of C^{++} language converts these pulses into values of force and displacement for an Excel sheet in real time.

3. VALIDATION PROCESS

In order to establish the accuracy of the tests carried out by FADECOM apparatus, a scientific cooperation agreement was signed in 2015 and renewed in 2017 between GDPPav, representing UFSC, and IFSTTAR, from Nantes, France, to compare the results obtained by both research centres taking into account a laboratory campaign considering dynamic (complex) stiffness modulus and fatigue crossed-tests.

High modulus asphalt mix with 0/12.7mm granitic crushed rock gradation and use of asphalt binder penetration 10/20 (0.1mm) was chosen to be tested. All the trapezoidal specimens were produced in GDPPav laboratory premised, in order to avoid scattered procedures and to keep the homogeneity of the samples.

The planning of the tests followed the standardized French specifications [7-8], which determine that at least 18 specimens (distributed equally among 3 different strain levels of evaluation) must be tested in a laboratory campaign on the fatigue behavior of a given asphalt mix and at least 4 specimens for carrying out complex modulus tests. They were carried out tests just in dry state.

In this particular research, 2 sets of 24 specimens were selected, distributed into 3 subsets of 8 units to be tested at each strain level for the fatigue tests, as well as 2 sets of 4 specimens for the complex modulus tests provided by the same asphalt mix slab as described in section 3.3.

However, to validate each set of specimens to be tested, they must comply with the limits defined by the rigorous statistical criteria of the standardized specifications. These criteria are the variation coefficient (≤1.0%), which is based on the results for the constant K_ε related to the geometric dimensions of each specimen, defined in Eq. (1), and the standard deviation (≤0.5) concerning the air void content of each set of specimens. If any specimen does not obey one of these criteria, it must be rejected before the beginning of the test and replaced by another suitable unit.

$$K_\varepsilon = \frac{(B-b)^2}{8.b.h^2.\left[\frac{(B-b).(3B-b)}{2B^2}+\ln\frac{B}{b}\right]} \quad (1)$$

where 'K_ε' is a constant related to the geometric dimensions of the specimens (mm^{-1}); 'h' is the height of the specimen (mm); 'b' is the small base of the specimen (mm); and 'B' is the large base of the specimen (mm).

The displacement amplitude applied by the oscillator rods on the small base of the trapezoidal specimens is calculated through Eq. (2), which is related to each strain level chosen arbitrarily by the designer.

$$f = \frac{\varepsilon_{max}}{K_{\varepsilon}} \text{; being the displacement amplitude calculated by } A = 2.f \qquad (2)$$

where 'f' is the half displacement amplitude applied to the small base of the specimen ($x10^{-6}$); 'K_{ε}' is the constant related to the geometric values of the specimens (mm^{-1}); ε_{max} is the maximum strain level correspondent to a given displacement amplitude ($x10^{-6}$); 'A' is the peak to peak displacement amplitude applied to the small base of the specimen ($x10^{-6}$). It must be remarked that 10^{-6} is the scientific notation for microstrains (μdef).

For fatigue tests, the adjustment of the displacement amplitude values calculated through Eq. (2) (Table 2) was measured with an accuracy of 1.0 μm, using an analogical extensometer, which was placed in the small base of the specimens.

TABLE 1 Strain levels chosen for fatigue tests and air void content of the asphalt mixes

Asphalt Mix	Temperature of Test	Strain Level ($x10^{-6}$)			Air Void Content (%)
		Sets of Specimens			
		8	8	8	
10/20	10ºC	120	135	150	4.2
10/20	30ºC	95	115	135	4.3

For all complex modulus tests, the displacement amplitude was calculated using the same procedure considered for fatigue tests, but fixed at 40 x 10^{-6}, as already mentioned in section 2.3, respecting the standardized maximum limit of 50 x 10^{-6} [8]. Besides, frequencies of 1Hz, 3Hz, 10Hz and 30Hz were applied. For each frequency, temperatures of -10ºC, 0ºC, 10ºC, 15ºC, 20ºC, 30ºC, 40ºC and 50ºC were simulated. The displacement amplitudes were gradually regulated by two Allen head screws connected to each eccentric axle (indication 2 in Figure 1). As a result of this laboratory campaign, Figure 2 presents the rheological behavior of the dynamic stiffness modulus represented in complex plan so-called Cole-Cole, comprising its real (E_1) and imaginary (E_2) components, while Figure 3 presents the fatigue resistance tests.

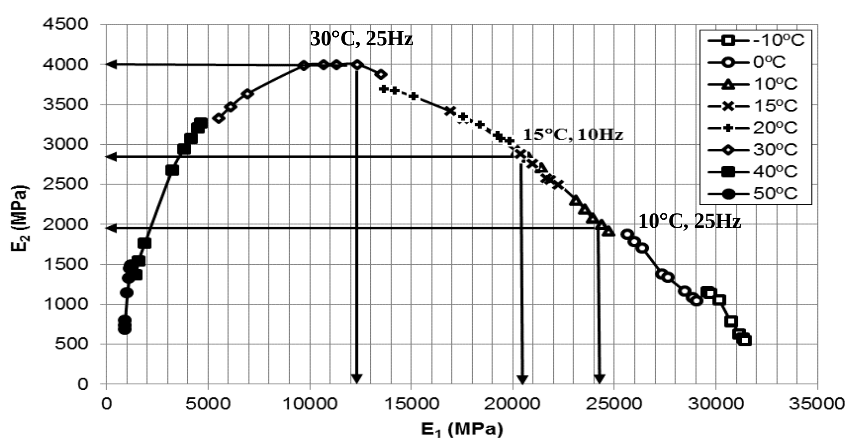

FIGURE 2 Rheological behavior of the asphalt mix in complex plan Cole-Cole

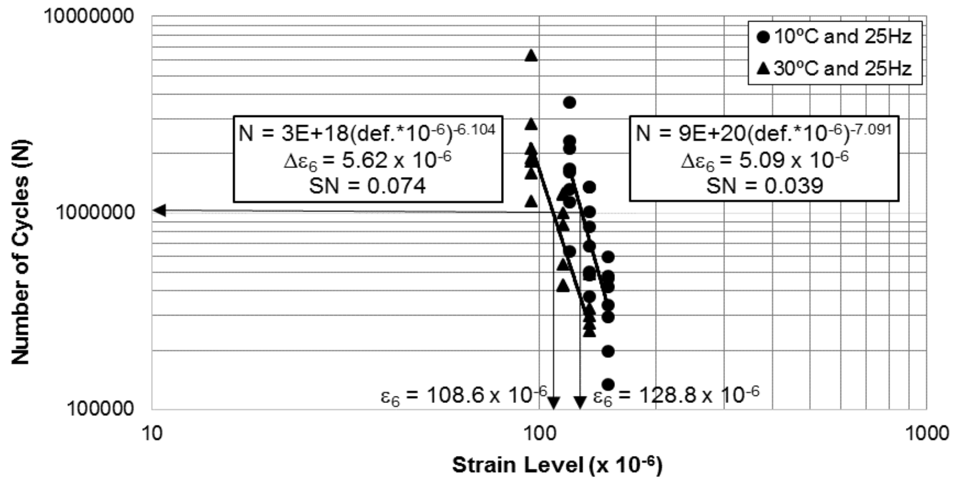

FIGURE 3 Fatigue curves from tests carried out at 10ºC and 25Hz, and at 30ºC and 25Hz

Table 2 summarizes the results obtained by the FADECOM and IFSTTAR apparatuses.

TABLE 2 Comparative results between FADECOM and IFSTTAR apparatuses

Dynamic Complex Stiffness Modulus Tests								
Test Condition	E_1[1] (MPa)	E_1[2] (MPa)	E_2[1] (MPa)	E_2[2] (MPa)	|E*|[1] (MPa)	|E*|[2] (MPa)	φ[1] (°)	φ[2] (°)
10°C and 25Hz	24786	24516	2031	2339	24871	24627	4.7	5.5
15°C and 10Hz	20719	19697	2917	3054	20926	19932	8.0	8.8
30°C and 25Hz	12020	10703	4018	3651	12677	11309	18.5	18.6
Fatigue Tests								
Test Condition	ε_6 ($x10^{-6}$)[1]				ε_6 ($x10^{-6}$)[2]			
10°C and 25Hz	128.8				130.2			
30°C and 25Hz	108.6				-			

[1]tests performed with FADECOM apparatus; [2]tests performed with IFSTTAR apparatus.

4. CONCLUSIONS

Analyzing data presented in Table 2, it is possible to infer that the scattering of results is less than 5.0% for dynamic (complex) stiffness modulus (|E*|), less than 1.0% for phase angle (º) and 1.0% maximum for fatigue strain at 10^6 loading cycles (ε_6), when compared the values determined by the FADECOM and IFSTTAR apparatuses. These trends are strongly lower than the standard deviation tolerances established by the French methodology [7-8], i.e., around 10% maximum for stiffness modulus and 3.0 ($x10^{-6}$) for ε_6 ($x10^{-6}$), demonstrating huge accuracy of the FADECOM apparatus and its feasibility to be applied in pavement design researches.

Acknowlegments
We would like to thank to the Institut Français des Sciences et Technologies des Transports, de l'Aménagement et des Réseaux (IFSTTAR) from Nantes, France, by the continuous scientific cooperation agreement with our Group of Research and Development in Pavement (GDPPav).

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