Fatigue Behaviour of a Dense Graded HMA Using the Four Point Bending Beam Test – Case Study in BR-116, Brazil.

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ABSTRACT

Fatigue is characterized by structural deterioration of a material when it is subjected to a state of repeated stress-strain cycles, thus resulting in cracking of the pavement and eventual failure after a sufficient number of load cycles. The laboratory test commonly employed in Brazil to analyse the fatigue life of asphalt mixtures is the indirect tensile test in cylindrical samples (IDT). Current design method for flexible pavements in the country take into account the asphalt's fatigue life courses based on such test. An alternative fatigue laboratory test is the four point bending beam tests (4PBBT) which has proved more effective when compared to field results, yielding to closer field to laboratory behaviour approximation. The present work examined the fatigue behaviour of an asphalt mixture with polymer-modified binder (PG 76-11) using both IDT fatigue test and 4PBBT. A road segment was instrumented monitoring mechanic responses in the asphalt layer allowing the comparison among all three situations: IDT fatigue, 4PBBT and in-service road. Results demonstrate the strain and stress levels on the asphalt layer enabling a better understanding of efforts developed in the structure. The results also demonstrate a closer relation between the 4PBB tests with in-service pavement fatigue development.

Keywords: IDT fatigue test, four point bending test, pavement instrumentation & fatigue performance model.

1. INTRODUCTION

The fatigue cracking is recognized as one of the main distress types in asphalt concrete pavements [1-2]. This phenomenon occurs due the accumulation of damage under the effect of repeated traffic loading. The tensile strain developed in the bottom of the wearing course leads the layer to cracking and consequent loss of structural capacity.

Various laboratory testing methods have been developed to characterize the fatigue response of asphalt concrete mixtures. In Brazil, the test commonly employed to analyse the fatigue life of asphalt mixtures is the indirect tensile test by diametrical compression in cylindrical samples (IDT). This test is relatively simple to conduct and low cost, but some known disadvantages, as permanent deformation on the loading strips, underestimates the fatigue life [3]. Nonetheless, four point bending beam tests have recognized better ability to simulate field conditions [4].

The monitoring of stresses and strains developed in pavement structures is of interest to pavement researches and engineers for the proper understanding of their structural behaviour, which is crucial to the pavement design, performance prediction and road management systems

[5]. The measuring of the mechanical and environmental response of an in-service segment through instrumentation allows the comparison with laboratory behaviour of the same asphalt mixture.

Pavement instrumentation can be an important tool to monitoring in-service material performance, structural responses under actual environmental and loading conditions, and also assist in calibration of models [6]. Various segments were instrumented for this purpose, allowing the validation and calibration of models that are actually used in mechanistic-empirical pavement design methods [7-9].

In roads under concession, the development of a significant superficial cracked area is not allowed by the control agencies, under penalty of a fine. Thus, a proper fatigue performance model is important to identify the right moment of an intervention or repair in the structure.

Thus, this research is divided in two stages, the field instrumentation of a segment in a federal highway under concession and laboratory tests. Since the relation between the field and laboratory response is considered a challenge for road engineers along the history.

2. EXPERIMENTAL INVESTIGATION

The instrumentation process of the road segment and laboratory tests are described below.

2.1 Field instrumentation

The structure of test section selected consists in a flexible pavement with a bituminous layer of a hot mix asphalt (HMA) with polymer-modified binder (10 cm thickness), a dense-graded aggregate base (15 cm) and granular subbase (30 cm) over a sandy subgrade.

Sensors embedded in pavement sections have proven useful in providing measured responses as a basis of comparison. Various researchers have instrumented pavement layers using strain gages and pressure cells to measure dynamic response to load in the form of strains and pressures [7, 10, 11-12]. In this sense, a road segment on BR-116/RS, in southern Brazil, was instrumented with these sensors in the bottom of asphalt wearing course.

The sensors, selected in accordance with literature and authors experience, include two pressure cells (PC) (FIGURE 1a), six strain gages (SG) (FIGURE 1b) and six thermocouples (FIGURE 1c). One of the pressure cells (model Geokon Earth Pressure Cell) have the capacity of 1.0 MPa (PC1) and the other 2.5 MPa (PC2), the strain gages (model Kyowa KM-120-120-H2-11-W1M) are oriented to measure longitudinal, transverse and 45° strain, and the thermocouples (model LM35) have the temperature range from -55 ºC to +150 ºC with ± 0.5ºC accuracy.


(a) (b) (c)

FIGURE 1 a) Pressure Cell; b) Strain Gage; c) Thermocouple

All the sensors are installed in the bottom of wearing course, the first set (PC2 + 3 SG) are spaced 5 m apart longitudinally from the second set (PC1 + 3 SG), and located under the external wheel path of the external track. The FIGURE 2 shows the sensor layout along the external wheel path.

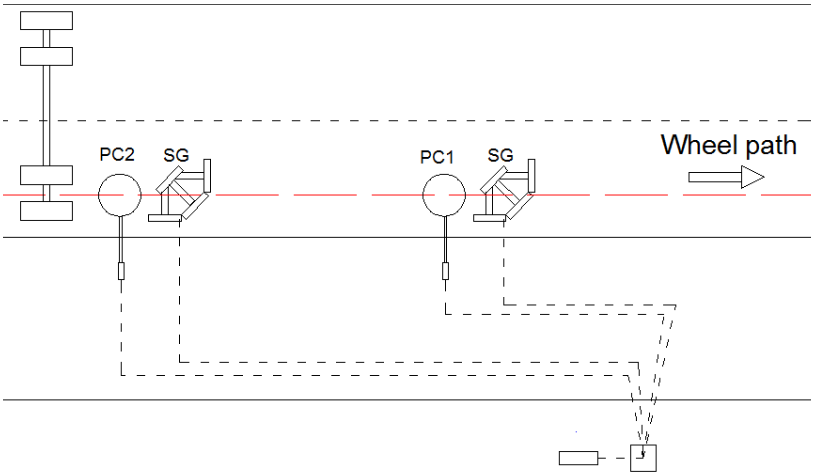


FIGURE 2 Sensors Installation Layout

A custom data acquisition system (DAS) was developed as part of this research. The DAS performs signal conditioning, analog signal filtering and amplification, digitization and data pre-processing before sending it to an embedded single board computer for storage. The pre-processing implements a high pass filter to remove base line level variations (caused mainly due to temperature variations) and a trigger algorithm that sends a flag indicating the start of a dynamic event. The event flag is set when the signal variation is higher than a user defined threshold. The system samples the analog signals at a rate of 450 points per second.

2.2 Laboratory tests

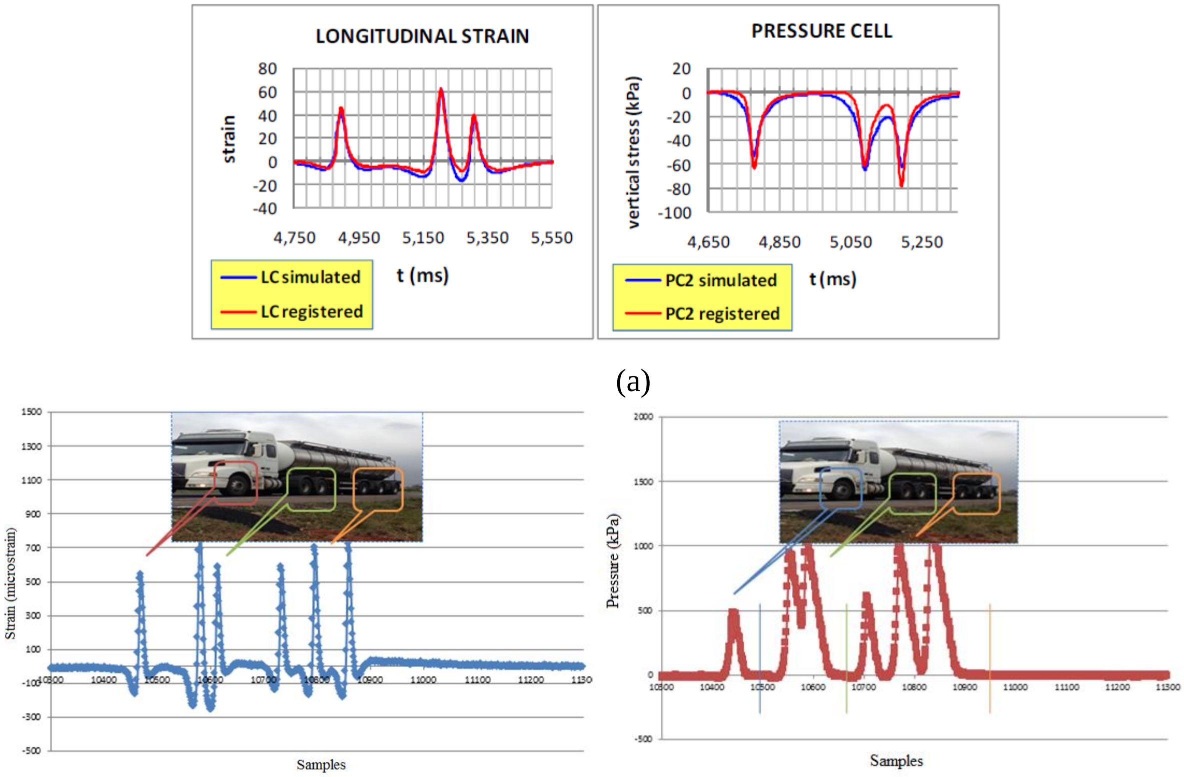
To evaluate the laboratory performance two test configurations were used, the indirect tensile test and the four point bending beam. The samples required for the tests were cored direct from the field, both cylindrical (IDT) and trapezoidal (4PBB), to evaluate the actual density condition and because the mixtures produced in an asphalt plant and in the laboratory may have differences in performance [13].

The IDT was conducted under stress controlled mode of about 10%, 20%, 30%, 40% and 50% the static tensile strength, in two samples per level. The 4PBB test were carried out under strain controlled mode of 400 microstrains (με), 500 με and 600 με, in three samples per level. The failure criteria adopted was 50% reduction in the initial resilient modulus for IDT and in the initial flexural stiffness for 4PBB, both in temperature of 20°C.

3. RESULTS

For validation of data acquisition system and instruments, the strains and stresses pulses obtained were compared to other researches results. The results seemed coherent and quite similar to literature review [8, 11, 14]. FIGURE 3 (a) shows the longitudinal strains and pressure cells signals simulated by pavement analysis software's and collected in field by instruments

[11]. The signals obtained in the present research have the same shape, enabling also the identification of different axles types (FIGURE 3 (b))



(a)

(b)

FIGURE 3 Experimental waves signal, for a three axle truck (a) [11], sensors readings and identification of different axles (b)

The longitudinal strain gage shows alternate signal of compression and tension, due to dynamic nature of the loads, which impose different efforts depending on the position of gage in relation to the axle [14]. The vertical stress is always compression.

In laboratory, the efforts are controlled by the test machines, differently from the field. In IDT the strains increase along the test, under the same level of controlled stress, due to reduction in resilient modulus of the sample. In the 4PBB the stress decrease along the test, under the constant level of controlled strain, also due to reduction in stiffness. The FIGURE 4 presents the fatigue results of both IDT and 4PBB fatigue tests.

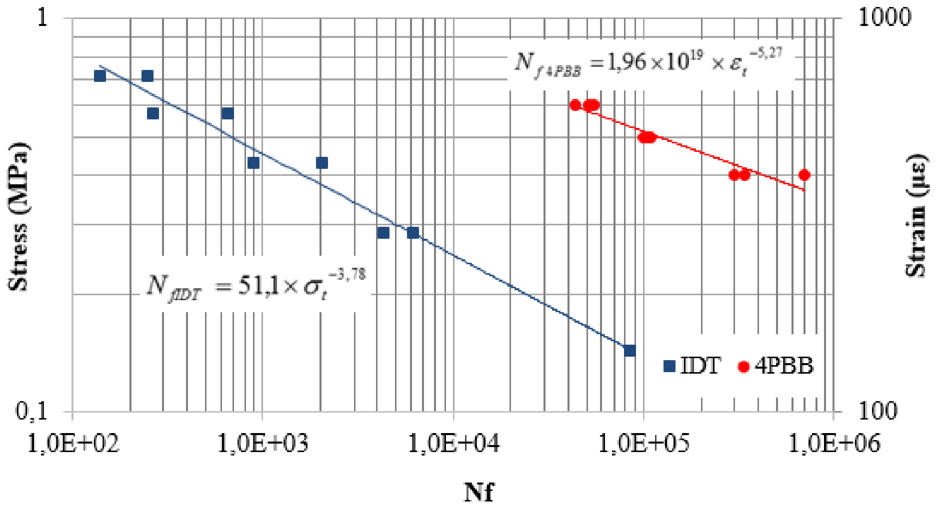
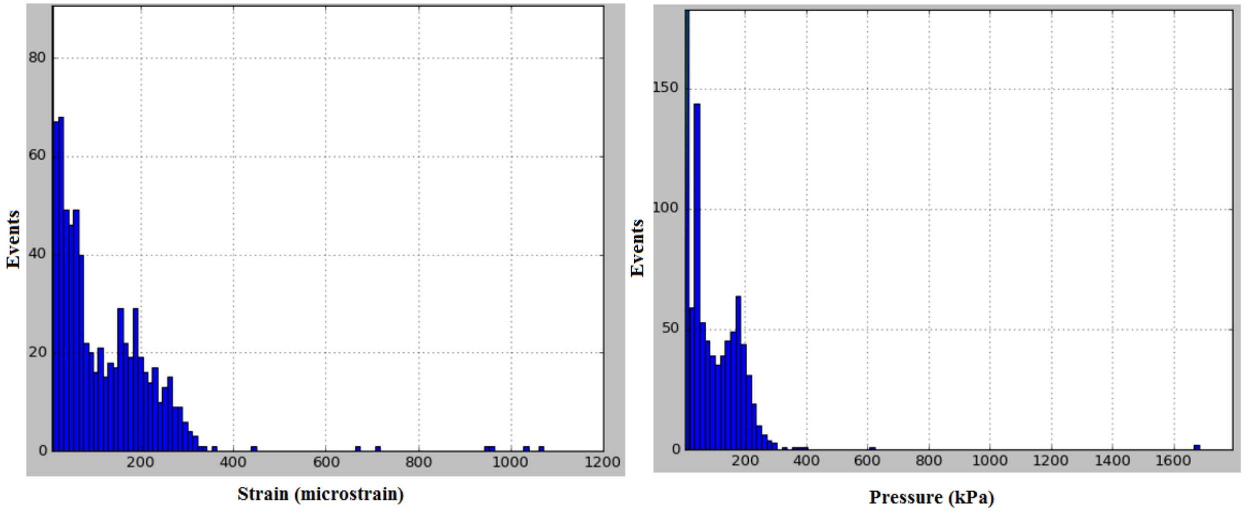


FIGURE 4 Fatigue results for both IDT and 4PBB fatigue tests

The fatigue results are typically adjusted by a curve in which is related the effort imposed in the test with the number of cycles to the failure - N_f (Wöhler curves). However, knowing the actual effort induced in the field is important to determine in which level the fatigue behaviour should be analysed, since the laboratory tests are carried out in different levels.

In this sense, a series of 1000 events were collected to determine the level of stress and strains developed in the bottom of asphalt layer. The results (FIGURE 5) demonstrates that the longitudinal strains and vertical stress rarely exceed 300 microstrains and 300 kPa, respectively.



(a) (b)

FIGURE 5 Serie of events collected for strain (a) and stress (b) in the bottom of asphalt layer

In laboratory, normally the strain level is higher than those obtained from the field data, to make the tests faster. In the strain level observed in field data (less than 300 με), the 4PBB shows a N_f=1.73*10^6, while IDT shows a N_f=1.41*10^2, demonstrating a longer fatigue lifecycle for 4PBB in relation to IDT, what was expected [4].

The number of repetitions of a standard axle (N) in the segment until now, based on the United States Army Corps of Engineers (USACE) method, is $N=4.15*10^6$, value higher than the N_f from fatigue tests, even considering the same tensile strain observed in field, but the pavement section does not develop superficial cracked area during this period. This occurs due to the need of a correlation factor, or transfer function, from the laboratory to field result [8, 15, 16].

4. CONCLUSIONS

The understanding on the efforts developed on the pavement structure has an important role in the fatigue behaviour, and the monitoring of the pavement mechanic response in-service, under actual traffic load conditions, by means of sensors embedded on asphalt layer has been demonstrated as a potential tool to access these data.

The data acquisition system developed has proven to be effective and the readings are reliable, according to the theory. The filtering and pre-processing of signals allows a loading wave shape without interferences, therefore becoming easily understandable and interpretable. The algorithm for identification of a new event is also adequate, showing a good sensibility for this application.

Even the pavement structure showing longer fatigue lifecycle than laboratory tests, the 4PBB have a closer relation with field performance, since that presents a N_f, for 300 $\mu\varepsilon$, approximately 10^4 times longer than in IDT test.

The pavement section does not develop superficial cracked area during the research period, but continues to be monitored, and it was expected that the pavement failure allows an accurate calibration of the concessionary fatigue model and laboratory to field correlation for both IDT and 4PBB tests.

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