Investigation of crack propagation in asphalt pavement structures using accelerated full scale test

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ABSTRACT

When reinforcing existing cracked asphalt pavements, the design and evaluation of the durability of the reinforced structure are quite different from those of a new pavement generally based on fatigue criteria deduced from stress and strain fields computed for the pavement without flaws. For the design of reinforcement solutions, the presence of cracks and their propagation need to be explicitly considered. In order to improve the understanding of bottom-up crack propagation in asphalt pavements, full scale pavement sections were constructed and tested. The experimental pavement section presented in this paper is composed of a layer of high modulus asphalt material (HMAM) at the bottom covered by a classical base course (BC) of asphalt material with lower performance. A vertical crack is initiated by placing a thin steel bar at the bottom of the asphalt layers. The full scale test was performed using the FABAC traffic simulator of IFSTTAR. More than 1.4 million of 65 kN dual wheel loads were applied. The initiation and propagation of cracks in the pavement structure could be effectively detected and followed from the experimental results obtained from embedded instrumentation and FWD measurements.

Keywords: Crack propagation, Asphalt pavement, Accelerated pavement testing

1. INTRODUCTION

Crack propagation in asphalt overlays is one of the main issues when designing reinforcement solutions for asphalt pavements [1-5]. Cracks propagate generally through the overlays over time from localized weak areas such as existing cracks or joints. They are mainly caused by traffic loading and temperature variation.

The objective of the present study is to investigate crack propagation mechanisms in asphalt pavement due to loading of heavy traffic. For that purpose, full scale structures are built and tested. This experimental study will serve further as a basis for validation and calibration of numerical models which are developed in parallel to the experimental part. Both these experimental and numerical studies will be applied then for comparison of different reinforcement solutions assessed against crack propagation criteria.

This paper first presents the investigated pavement and the asphalt materials used for its construction. The full scale test using the IFSTTAR's FABAC traffic simulator is then described. Finally experimental results obtained from embedded instrumentation and falling weight deflectometer (FWD) are reported and analysed.

2. PRESENTATION OF PAVEMENT SECTIONS AND ASPHALT MATERIALS

2.1 Pavement sections

The study reported in this paper is part of a larger research program for which two similar full-scale pavement sections were constructed and tested with the aim of comparing their performance against crack propagation. These sections were composed of layers of same thickness but incorporating different types of asphalt materials from one structure to another. However, to respect the prescribed length of paper, only one of the tested pavement sections is presented hereafter. This section is composed of a layer of high modulus asphalt material (HMAM) lying under a classical base course (BC) of asphalt material with lower performance. The total thickness of the two asphalt layers is 11 cm (6 cm for the lower layer and 5 cm for the upper layer) (figure 1).

The subgrade of the pavement has a mean load-bearing capacity, measured at different locations by means of the plate test, of about 70 MPa. A tack coat of 300 g/m² (residual) is applied at the interface between the two asphalt layers using a classical cationic rapid setting bitumen emulsion.

Monitoring of this pavement section during testing is performed using the embedded instrumentation shown in figure 1.

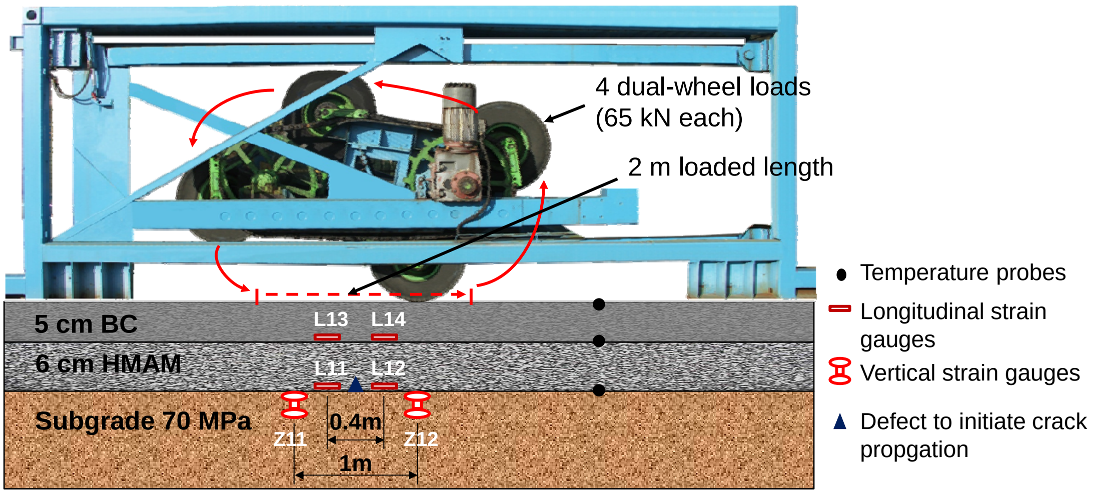

FIGURE 1 IFSTTAR's FABAC traffic simulator and the tested pavement structure

2.2 Characteristics of the asphalt materials

Both asphalt mixtures have similar proportions of aggregates with the same maximum aggregates size of 10 mm. The binder contents of BC and HMAM are 4.2% (35/50 penetration grade) and 5.6% (10/20 penetration grade) per dry weight of aggregates, respectively. The temperatures for building of BC and HMAM layers in pavement are 160°C and 180°C. Complex moduli and fatigue resistances of the two asphalt mixtures are determined in the laboratory according to standards EN 12697-26 and EN 12697-24, respectively. These tests are performed on specimens built up from the materials of the pavement sections extracted during the construction phase. These mechanical properties will be useful to the modelling step of the tests which, as mentioned earlier, is not presented in this paper.

3. ACCELERATED FULL-SCALE TESTS

3.1 Testing conditions and instrumentation

For this study, two linear heavy traffic simulators of IFSTTAR, called FABAC machines (figure 1) were used. These two machines are similar and can be used simultaneously to test two full-scale pavement sections under quite identical loading and environmental conditions. Each machine has four load modules mounted in the same configuration of dual wheel loaded at 65 kN (half of the French standard axle load, which is 130 kN). The effective loaded zone has a length of 2 m. The loading speed was set to 3.6 km/h and more than 1.4 million of loads were applied without lateral wandering to the experimental pavement sections.

To accelerate damaging of the structure and favour initiation of bottom-up cracking, an artificial flaw represented by triangle-shaped steel bars was purposely placed at the bottom of the HMAM layer (figure 1). The steel bars were laid transversely to the wheel path axis. From this setup, a crack was expected to initiate at an early stage and propagate transversely to the wheel path axis through the asphalt layers up to the surface.

The pavement responses during testing were followed using embedded sensors. Under the wheel path and from both sides of the defect, longitudinal and vertical strain gauges were installed at the bottom of each asphalt layer and at the top of the subgrade, respectively (figure 1). Temperature sensors were placed at three different heights in the pavement (0, -5 and -11cm). During the test, the temperatures recorded in the asphalt layers were mostly between 5 and 25°C (figure 3).

3.2 First analyses of the pavement response

3.3.1 Experimental results from embedded sensors

Plenty of consistent experimental data (temperatures, longitudinal and vertical strains at several locations, deflection…) were recorded during this test. These are meant to be used along with numerical simulations to interpret the development of crack patterns in the pavement structure and also to investigate other unexpected phenomena that might have occurred during the test. However, this is beyond the scope of the present paper in which only some experimental results are commented.

As an example of collected information, figures 2 and 3 show data related to the measurements recorded by the longitudinal strain gauges. Furthermore, figure 4 shows a picture of the pavement surface after 1 million loading cycles attesting that damaging has indeed occurred since cracks are visible (white lines). These apparent cracks are located right above the area of the defect.

Again for the sake of conciseness, we focus herein on explaining figures 2 and 3 which allow us to highlight in a simple way changes in the pavement response with the increase of the number of load passing.

Figure 2 shows some horizontal profiles with respect to the moving load direction of longitudinal strains recorded by gauges L11, L12 (at the bottom of the HMAM layer) and L13, L14 (at the bottom of the BC layer) (see figure 1) for some selected numbers of loading cycles (3680; 100,000; 200,000; 300,000). At loading cycle 3680 (early stage of the test), the gauges exhibit quite similar signals from one to another side of the defect (comparison between L11/L12 and L13/L14). Extensional strains are recorded at the bottom of the HMAM layer whereas

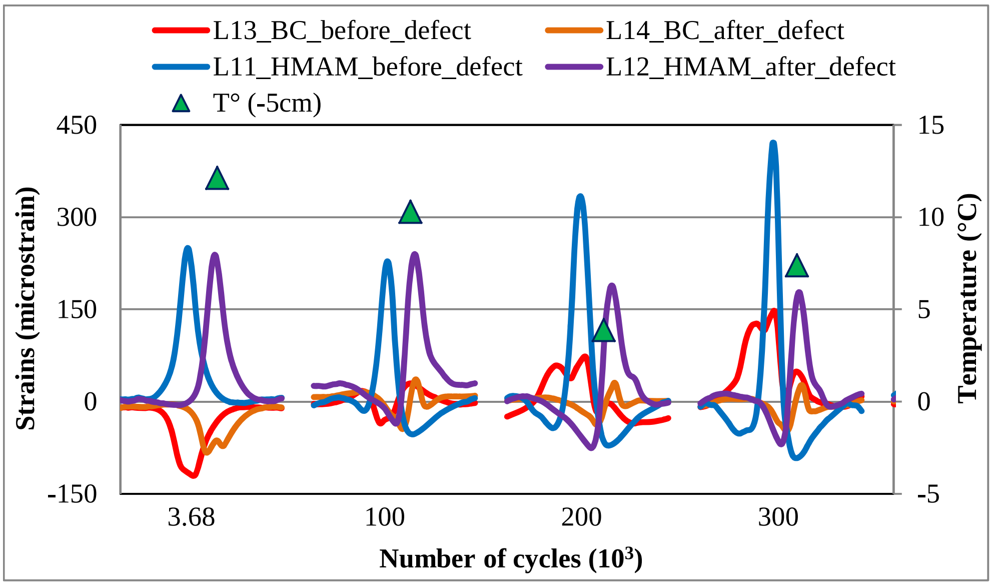

FIGURE 2 Longitudinal strain profiles recorded by the gauges positioned in the asphalt layers at some selected numbers of repeated loading cycles

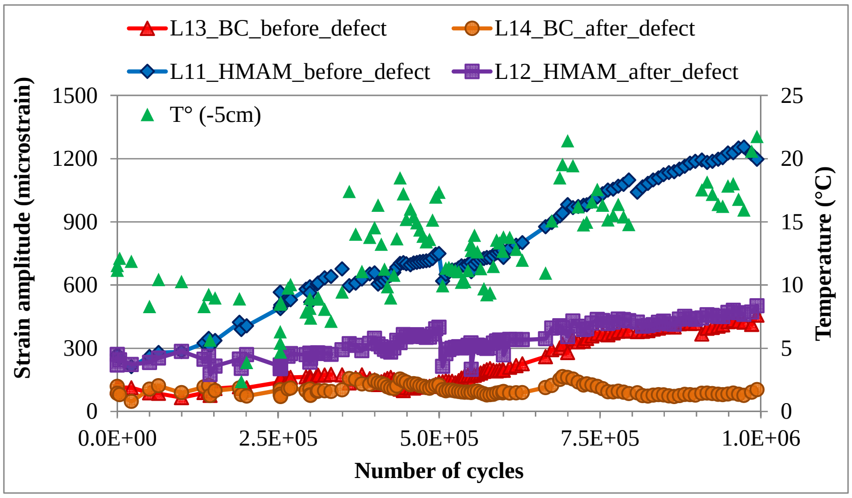

FIGURE 3 Strain amplitudes in the asphalt layers measured all along the test

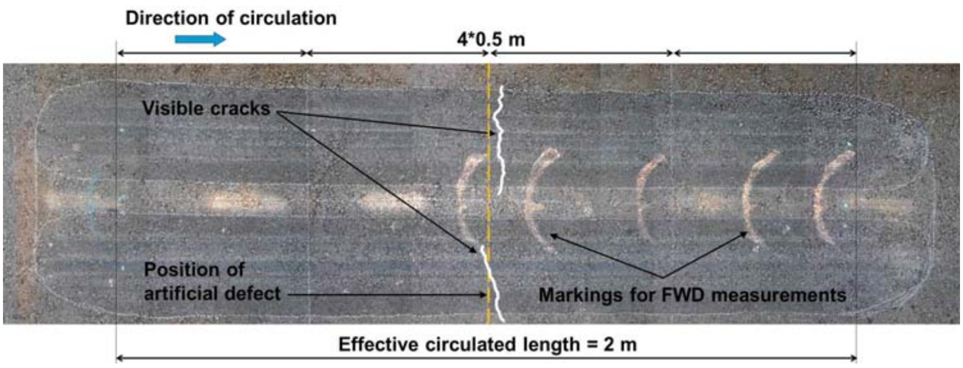

FIGURE 4 Top view picture of the pavement section after 1 million loading cycles: close-up of wheel path

compression is recorded right above the interface between the two asphalt layers, attesting that at this time the interface is bonded and the apparent neutral axis of the bituminous layers is below the interface. In addition, it can be shown that the response reflected by the gauge measurements is close to that of the sound pavement section without defect computed using software Alize-LCPC (based on Burmister formalism).

At loading cycle 100,000, the strains measured from both sides of the defect still show similar evolution at the bottom of HMAM and BC. However, the strain magnitude recorded right above the interface (L13 and L14) have narrowed and moved around zero as compared to loading cycle 3680, as if the apparent neutral axis of the asphalt layers in the vicinity of the defect had stepped forward to the top. This effect could probably be attributed to a crack which propagated vertically from the defect to close to the interface and still yield a strain response symmetric with respect to the vertical axis crossing the defect.

Then the symmetry of the strain response from both sides of the defect is lost (loading cycles 200,000 and 300,000). The strains measured by the gauges located ahead of the symmetry axis whatever the depth (L12 and L14) remain quite unchanged at loading cycles 200,000 and 300,000. However, the strains measured for the gauges located backward to this axis (L11 and L13) still evolve. In particular, the longitudinal strain measured in the BC layer (L13) exhibits a change in trend from contraction at launching of the test to extension at these numbers of cycles. This could reflect the bifurcation of the aforementioned vertical crack along the interface (towards L13) once it has reached this location leading to partial debonding between the asphalt layers. This could also be explained by initiation of a new crack in the vicinity of L13.

Figure 3 shows absolute strain amplitudes in the asphalt layers measured all along the test up to 1 million cycles. It confirms the continuation of the loss of symmetry of the pavement response as observed in figure 2 for the first 300,000 cycles. The strains recorded by the gauges located backward to the symmetry axis keep evolving during testing (from 100 to 400 and from 300 to 1,200 microstrains for L13 and L11, respectively) whereas those recorded by the gauges located ahead of the symmetry axis do not evolve (L14) or only very slightly (L12). These observations tend to consolidate the cracking scenario aforementioned that probably develops again as a vertical crack in the BC layer after partial debonding of the interface backward to the symmetry axis.

The forensic investigation of the pavement section as well as numerical simulations of some degradation scenarios (such as above) should help to elucidate the actual damaging process that took place during the test.

3.3.2 Results from FWD measurements

In addition to the experimental data recorded by the embedded instrumentation, deflection measurements by means of FWD were performed during planned short stops of the FABAC machines. These were carried out using the loading plate of 0.3 m in diameter loaded at 65 kN (same load magnitude as the FABAC loading). The results from three FWD campaigns performed at the initial stage (prior to any loading) and after 0.35 and 1 million of loading cycles are presented below. During each test campaign, the FWD load was carried out every 0.1 m along the test track (in the direction of the FABAC moving load). The locations of the FWD loading pad during each campaign were marked in order to be sure that tests from different campaigns were performed at these same locations (figure 4).

Figure 5 shows for the three campaigns the deflection measured by the first sensor located under the FWD load moved step-by-step every 0.1 m. Prior to the FABAC loading cycles, the deflection is not uniform due to some slight differences in the stiffness of the pavement foundation from left to right of the defect (located in x=0). This impacts all the three campaigns. Then as compared to the first campaign, the FWD tests performed after 350,000 fatigue loading cycles exhibit a global increase of the deflection on the area circulated by the FABAC loads (from -1 to 1m). As confirmed by the vertical deformation recorded at top of the subgrade, a loss in the bearing capacity of the pavement foundation seems to be responsible for this effect. This loss might be explained by suction of pore water induced by pumping under loading. Apart from this global increase, we also notice some local peaks of deflection. The first peak is located in the middle of the circulated length right above the artificial defect and can probably be attributed to a crack that developed from the defect (already noticed in strain gauge measurements). Besides, numerical simulations have shown that the presence of a vertical crack few centimetres high at the bottom of the HMAM layer could result indeed in such peak of deflection [6]. Two other peaks are located at 0.4 m backward and 0.5 m forward to the symmetry axis. These locations are at distances from the defect corresponding to the positioning of the vertical strain gauges on top of the subgrade. These strain gauges may also be considered as artificial flaws in the pavement from which cracks could initiate and propagate.

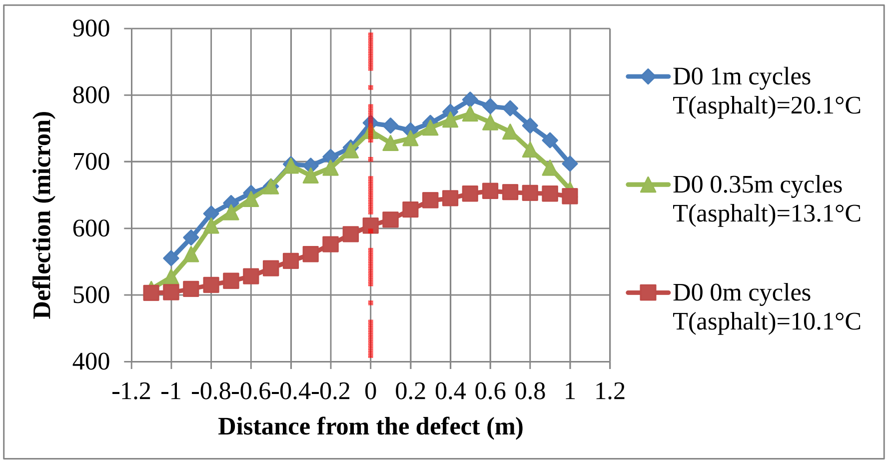

FIGURE 5 Maximum deflections under the 65 kN FWD at every 0.1 m along the 2 m circulated length

4. CONCLUSION

The present study investigates crack propagation mechanisms in asphalt pavement using accelerated pavement testing. For this project, full scale pavement sections composed of different asphalt materials corresponding to different design or reinforcement solutions were built and tested under the same conditions to enable future comparison. Experimental results obtained from one pavement section were presented in this paper. These have shown that the collected data allowed us to detect and follow the initiation and propagation of cracks during the fatigue full scale test, even before any visible sign at the pavement surface.

Full results of the accelerated full scale tests with comparison of crack propagation for the different construction solutions investigated, as well as numerical modelling for analysis of the experimental findings are being conducted [6] and could be presented in an extended version of the paper.

5. REFERENCES

[1] Goacoulou, Marchand, Mouratidis, La méthode des éléments finis : application à la fissuration des chaussées et au calcul du temps de remontée des fissures, Bulletin de liaison des laboratoires des ponts et chaussées, N°125, p76-91, 1983.

[2] Laveissière, Modélisation de la remontée de fissure en fatigue dans les structures routières par endommagement et macro-fissuration, PhD dissertation, Université de Limoges, Egletons. 2002.

[4] Hornych, Kerzrého, Chabot, Bodin, Balay & Deloffre, The LCPC's ALT facility contribution to pavement cracking knowledge, 6th Rilem Conference on Cracking in Asphalt Pavement, Chicago, 2008.

[5] Lytton, Tsai, Lee, Luo, Hu & Zhou, Models for Predicting Reflection Cracking of Hot-Mix Asphalt Overlays, NCHRP report 669, 2010.

[6] Nasser, Méthode de résolution du M4-5n par éléments finis mixtes pour l'analyse des chaussées avec discontinuités. PhD dissertation, Ecole Centrale de Nantes, Université Bretagne Loire. 2016.