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Transport Research Arena (TRA) Conference

Evaluation of the mechanical response of bituminous pavement surface layer with and without tack coat

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Abstract

Pavement surface layers are submitted to severe loading conditions, as they are directly in contact with tire loads, and present different types of damage: top down cracking, rutting, surface polishing. The purpose of this paper is to analyse the strain distribution at the interface between two asphalt layers and to quantify the influence of its viscoelasticity on the stresses and strains in the asphalt layers, in order to understand their damage mechanisms. The pavement response is evaluated by a full-scale pavement test, and modelled using the Viscoroute software. Three models are compared : (1) linear elastic (2) viscoelastic with bonded interface and (3) viscoelastic with a viscoelastic interface. The measurements and the modelling results indicate that the interface bonding condition has a strong influence on the mechanical behavior of the surface layer and on its damage mechanisms.

Keywords: Wearing course; modelling; failure mechanisms; viscoelasticity; interface;

1. Introduction

Flexible pavements are subjected to several types of cracking deterioration resulting from heavy vehicle loading under different climatic conditions. Two types of surface cracking, characterized by their initiation and propagation mechanism, can be defined. The first type called fatigue cracking, is generated by the bending of the bituminous layers, imposing a tensile stress and consequently a tension deformation at the base of the asphalt layers. This bottom-

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up cracking propagates upwards, until it reaches the surface. The second type of cracking is called top down cracking (TDC), that initiates near the pavement surface and spreads towards the base of the pavement.

Top down cracking (TDC) is one of the damaging modes that initiate near the surface of bituminous pavements. According to Grellet et al. (2018), the tensile stresses and strains occurring near the pavement surface under tire loading, and at the interface between two asphalt layers, are some of the main causes of TDC. The near surface stress/strain states depend on temperature conditions and on interface bonding conditions as shown in Wang and Al-Qadi (2010).

In the Binary project, the quantification of stresses and strains in the bituminous surface layers is conducted through experimental tests in the laboratory and in full scale, using an accelerated pavement test, carried out on 4 different pavement structures. Besides, numerical simulations using the pavement modelling software Viscoroute, are performed in order to compare with the experimental results. Different sensors are used to monitor the behavior of the full-scale pavement structures. Fiber optic sensors, installed in the bituminous layers are used to measure strains below and above the interface between two layers. Transversal and longitudinal gages and geophones, are used to measure the strains and deflections at the base of the surface layer respectively. Moreover, the real pressure distribution under the tires is measured using a contact pressure measurement system (Tekscan). Temperature probes also measure the temperature variations with layers depth.

In this paper, first results of the full-scale pavement experiment from two instrumented structures were selected to analyse the strain distributions obtained under tire loading above an interface between two asphalt layers. These results are compared with pavement simulations with the software Viscoroute, incorporating the Huet-Sayegh viscoelastic model for bituminous materials. The model parameters are determined from complex modulus tests. The sensor measurements are used to calibrate the modelling results. The modelling associated with the measurements, is then used to analyse the stress and strain fields produced by the tire loads in the surface layers, for different loading conditions (temperatures, load levels, loading speeds, lateral positions). These results allow to understand better the most critical loading conditions, and the failure mechanisms of surface layers. The final objective of this work will be to develop design criteria for pavement surface layers, which do not exist, at present, in most pavement design methods. This will also allow to evaluate better the impact of different types of heavy vehicle configurations, and types of tires on pavements.

2. Material characterization

The pavement structures used to analyze the distribution of strains above the interface (structure S2), consist of 60 mm of semi-coarse asphalt concrete (BBSG), resting on an existing 40 mm thick layer of asphalt base course material; a 750 mm thick granular subbase, and a sandy subgrade soil. During the construction, the surface course was applied without tack coat on section S2a. On section S2b, a tack coat, consisting of a classical cationic rapid setting bitumen emulsion (following EN 13808), was applied (with an application rate of 300 g/m² in residual bitumen) before laying the surface course, to ensure good bonding between the bituminous layers.

3. Experimental campaign

The full-scale experiment of the Binary project is carried out on the accelerated pavement testing (APT) facility (also called fatigue carousel) of Gustave Eiffel University (Nantes, France). The fatigue carousel is an outdoor test facility, which allows to test pavements in full scale, under heavy vehicle loads. It has a circular test track, with a diameter of 40 m, and four loading arms, which carry the loads. In this experiment, the track was divided into five sections, of which two are analyzed in this paper.

The structures of the two pavement sections are shown in Fig.1. Both structures had the same bituminous concrete (BBSG) wearing course, but with different interface bonding conditions. These sections were instrumented with strain gauges, measuring the longitudinal and transversal strains at the bottom of the surface course, optical fibers also

measuring the strains, and temperature sensors. Different loading tests have been carried out with the APT facility, using dual wheels, circulating at different speeds, and with different loads. Two experimental conditions are detailed in this paper, corresponding to:

- A load of 4.5 tons, and a temperature in the middle of the surface layer of 7.8°C.
- A load of 5.5 tons and a temperature of 12°C.

In all the cases, different speeds were applied, with the wheels in the central position (without lateral wandering). In this paper, the strains measured at the bottom of the surface layer (in two directions: longitudinal ϵ_{xx} and transversal ϵ_{yy}) are analyzed.

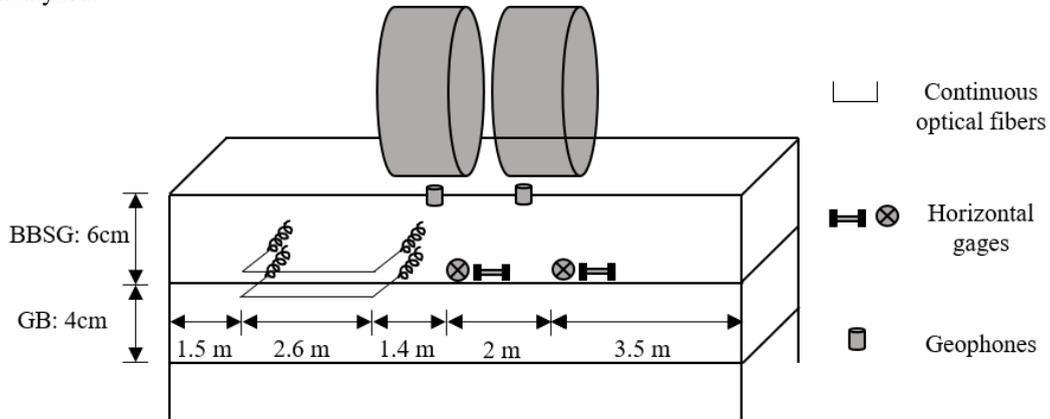
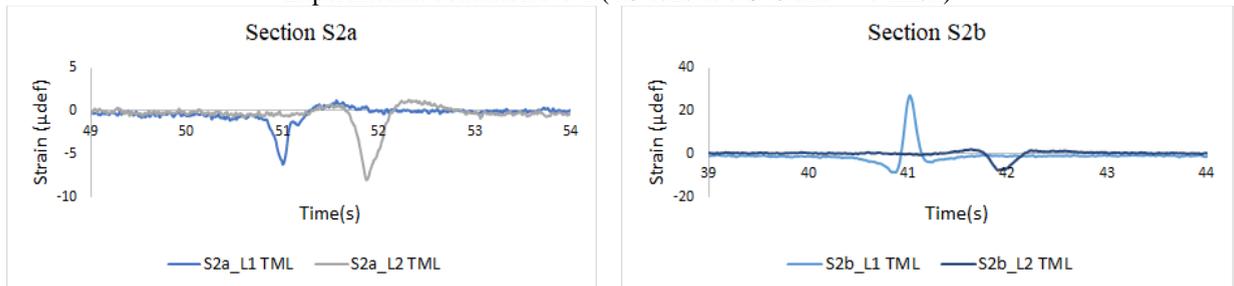


Fig.1. Instrumentation of the structure S2a

4. Experimental strains measurements above the interface

The longitudinal and transversal strains are measured at a depth $z=52.5$ mm, by the gages installed at the base of the surface layer. Fig.2 presents the longitudinal strain signals measured under the tire (at $y = 0$), corresponding to the central position of the carousel, for the two selected experimental conditions and for both sections S2a and S2b. For section S2a, without tack coat, the strains are negative (in compression). For section S2b, with tack coat, the two gages give different signals. One gage gives a signal with a negative peak (in compression), while the other gage gives a positive peak (tension).

Experimental condition No.1 (4.5 tons at 7.8°C and $v=7$ km/h)



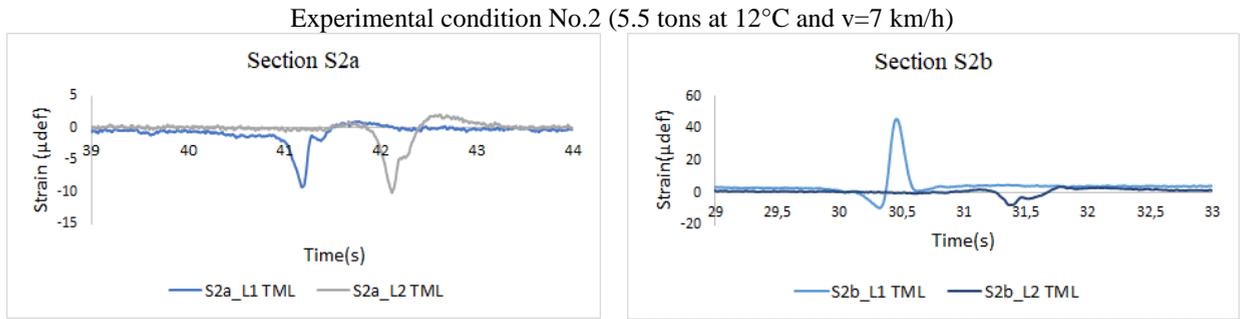


Fig.2. Experimental longitudinal strain signals at the base of surface layer (ϵ_{xx} at $z=52.5$ mm)

Fig.3 presents the transversal strain signals obtained for the 2 experimental conditions, for sections S2a and S2b. For both tack coat conditions, the deformations are negative, and the amplitude increases as the load and temperature increase.

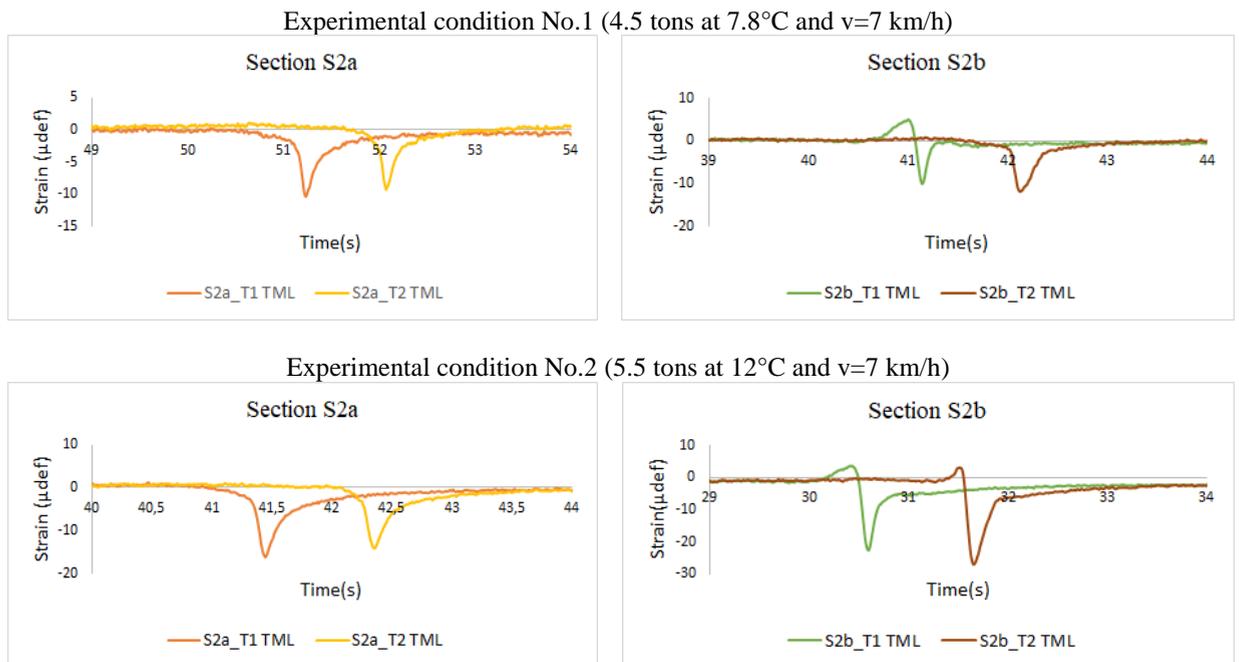


Fig.3. Experimental transversal strain signals at the base of surface layer (ϵ_{yy} at $z=52.5$ mm)

5. Pavement modelling

The modeling of the pavement response was performed using the ViscoRoute© 2.0 software (Chabot et al. 2010). Viscoroute is a semi-analytical, multilayer pavement modelling tool, which allows to consider elastic materials, and viscoelastic materials, described by the Huet-Sayegh model (1965), as well as different load shapes (rectangular, elliptical).

The Huet-Sayegh model represented in Fig.4 is adapted in the analytical calculation. This rheological model allows to represent correctly the viscoelastic behavior of bituminous layers over a frequency range. The model consists of two springs with stiffnesses E_0 and E_∞ , characterizing the linear elastic behavior of the material, and two nonlinear dampers with parameters k and h modeling the viscous behavior of the material.

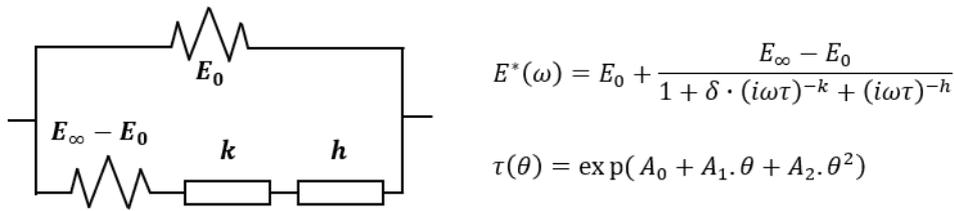


Fig.4. Huet-Sayegh model

In this study, the soil and the granular base were simulated as elastic materials. The soil modulus was back-calculated from falling weight deflectometer tests (FWD). The asphalt layers were considered visco-elastic, and their properties were calculated from laboratory complex modulus tests.

For the modelling of the interface between the asphalt layers, two assumptions were considered in this paper. The first assumption consisted in considering a perfectly bonded interface, leading to continuity of displacements and vertical stresses between the two bituminous layers. According to Grellet et al. (2018), this bonded condition generally remains valid for temperatures between 10°C and 25°C, where the binder and asphalt are neither too rigid nor too viscous. For temperatures above 25°C, the binder behaves like a viscoelastic material and the bonded condition is not anymore valid. In this case, the interface will be modelled as a thin layer with a viscoelastic behavior. The viscoelastic behavior of the interface layer and of the bituminous layers are both characterized by the Huet-Sayegh model. Again, according to Grellet et al. (2018), the best predictions of interface behavior are obtained by considering a thickness of the interface of 0.5 mm, and viscoelastic properties corresponding to those of a bituminous binder (shown in Table 1). In this paper, different interface thicknesses are tested.

Table 1. Material properties of the pavement layers

Viscoelastic materials								
Coefficients	δ	k	h	$E_\infty(\text{MPa})$	A_0	A_1	A_2	$E_0(\text{MPa})$
BBSG	2.59	0.22	0.66	33142	4.37	-0.39	1.31×10^{-3}	2.94×10^{-9}
Interface	3.79	0.25	0.78	1625	-2.79	-0.38	2.31×10^{-3}	-
BB	1.37	0.21	0.69	36069	2.88	-0.39	1.97×10^{-3}	48.22
Elastic materials								
Coefficients				$E(\text{MPa})$	Thickness(mm)			
Granular subbase				160	750			
Soil				95	∞			

6. Comparison between the strain measurements and the simulation results

The longitudinal and transversal strains obtained experimentally with the gages (Experimental condition No.2) are compared with the results of the numerical simulations, using successively the three models. Fig.5 and Fig.6 present respectively the longitudinal and transversal strains calculated at the center of the sensor corresponding to $z=52.5$ mm for sections S2a and S2b. For both sections, it can be seen that the linear elastic model (LE with bonded interface) cannot predict correctly the response of the surface layer. Much more realistic results are obtained using the viscoelastic model.

For section S2a (gages L1 and T1), the compression observed above the interface corresponds well with a linear viscoelastic simulation with bonded interface (LVE with bonded interface) in the numerical model. This tends to indicate a good bonding between the two asphalt layers. For section S2b (gages L1 and T1), the use of a thin viscoelastic interface layer leads to the best prediction of the strains in tension observed at the base of the first layer.

This tends to indicate that there is some sliding at the interface on this section. The modelling results vary with the assumption made for the thickness of the interface, with a best fit obtained for a thickness of 1 mm.

From the experimental results (Fig.2), at the base of section S2b, two types of signals are observed at two different gage positions. For the first gage L1, a tension is observed at the base of the first layer indicating some sliding at the interface. The second gage S2, at the base of the layer, undergoes a compression indicating most likely a bonded interface. So, it can be assumed that different bonding conditions exist for the same structure at two different gages position.

The strain measurements, confirmed by the modelling results, indicate that a same pavement section can present variable bonding conditions, and that at points where the bonding is not sufficient (Fig.5b and Fig.6b), relatively high longitudinal tensile strains can develop at the bottom of the wearing course, which can lead to fatigue and cracking of the surface layer, under repeated loading.

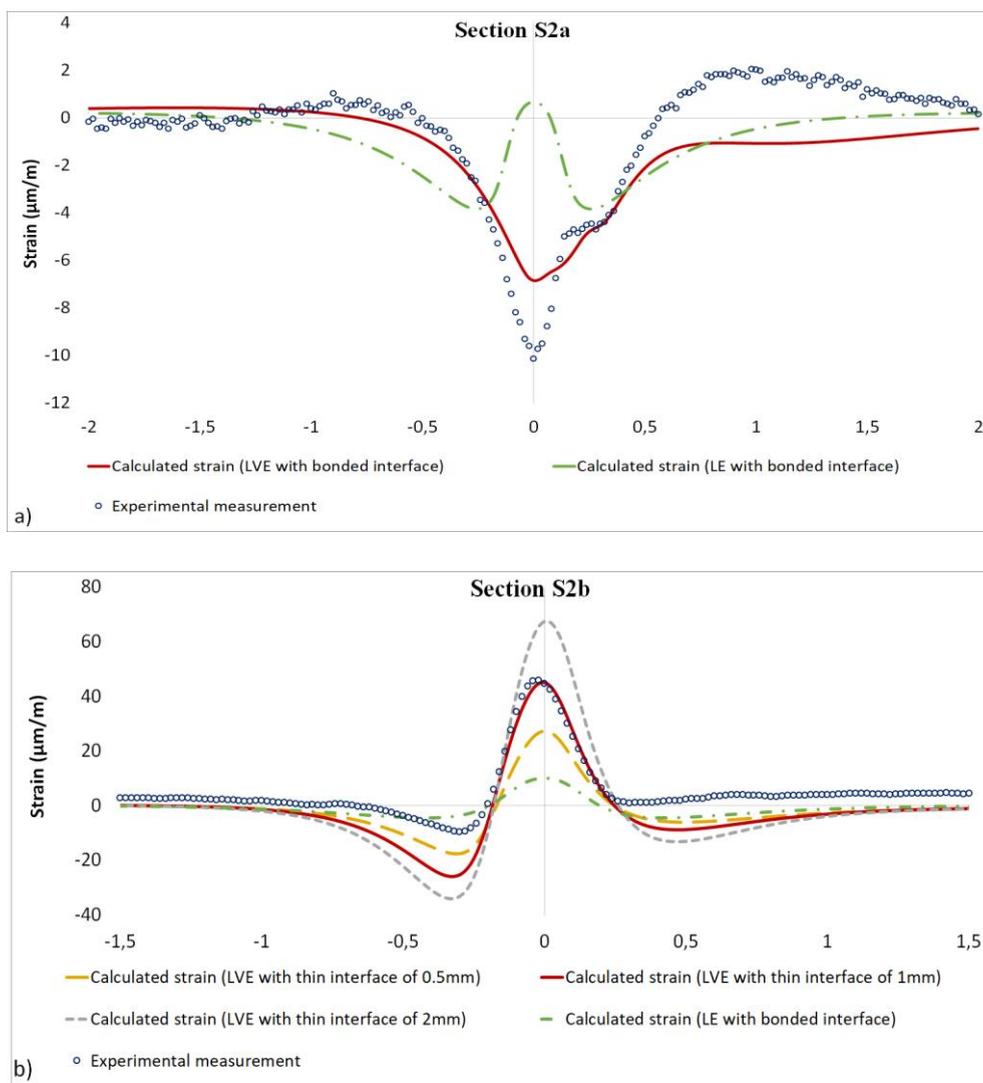


Fig.5. Comparison of numerical simulations and experimental measurements of longitudinal strains: a) in section S2a (without tack coat at the asphalt layers interface); b) in section S2b (with a tack coat)

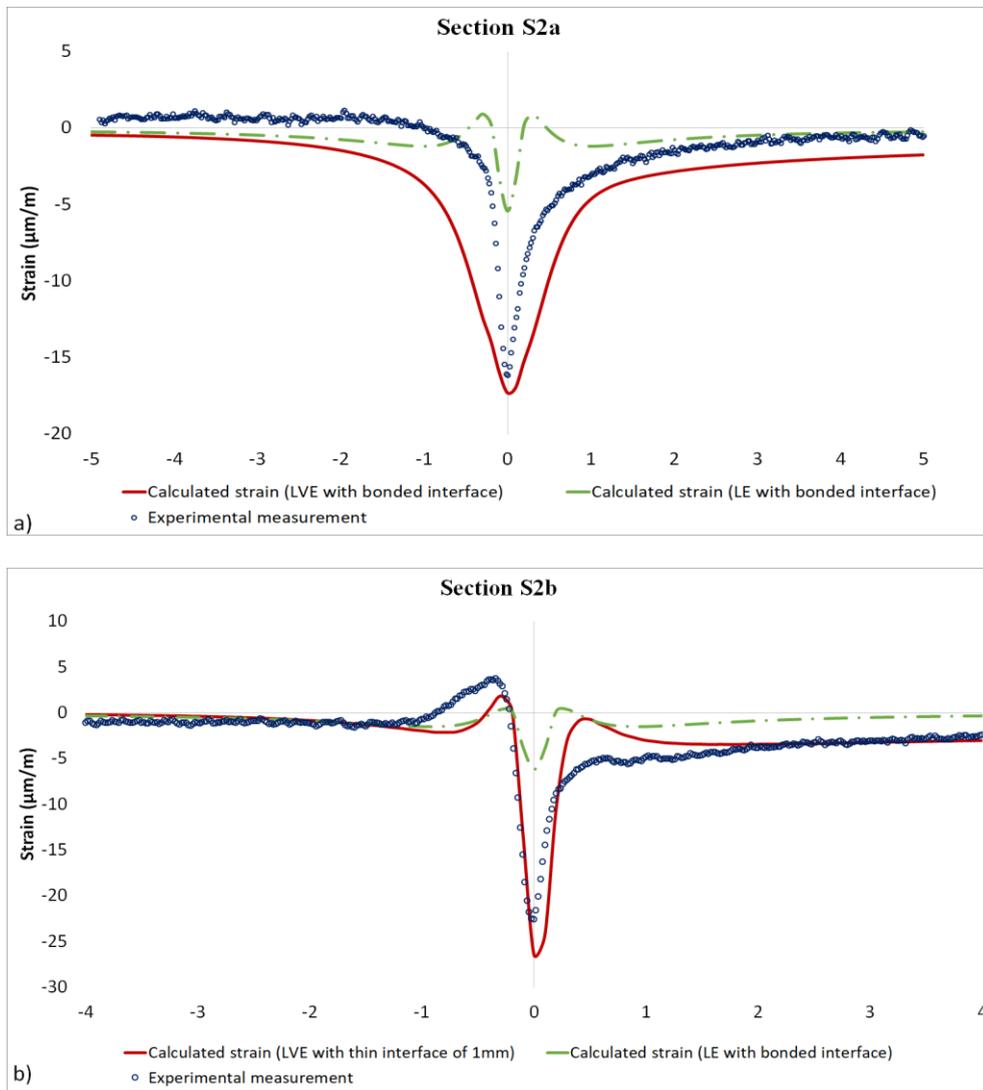


Fig.6. Comparison of numerical simulations and experimental measurements of transversal strains: a) in section S2a (without tack coat at the asphalt layers interface); b) in section S2b (with a tack coat)

7. Conclusion

The paper presents strain measurements made on two experimental sections tested in a full-scale APT experiment, at the bottom of the surface layer. The measurements, made just above the surface layer interface indicate different bonding conditions on the two sections. On the section without tack coat (S2a), measured strains were all in compression, indicating satisfactory bonding between the asphalt layers. On the section with tack coat (S2b) however, variable bonding conditions were observed, with on strain gage giving relatively high strains in tension, which could be explained by some sliding at the interface.

The behavior of the interfaces was confirmed by the modelling of the two sections with the Viscoroute software. For section S2a, the strains in compression could be well predicted with a bonded interface. On section S2b, to predict the

strains in tension, it was necessary to describe the interface as a thin viscoelastic layer, with a low complex modulus. The best fit with the experimental results was obtained with a 1 mm thick interface layer.

Finally, the results obtained in this work clearly show that the interface bonding condition has a great influence on the mechanical behavior of the bituminous surface layer and that insufficient layer bonding can generate significant tensile strains at the bottom of this layer, which could be one of the mechanisms of deterioration of surface layers.

References

- Al-Qadi, I., Wang, H., 2009. Evaluation of pavement damage due to new tire designs. Illinois Center for Transportation.
- Autret, P., De-boissoudy, A.B., Gramsammer, J.C., 1987. The circular test track of the Laboratoire Central des Ponts et Chaussées – First Results. Proceedings of 6th International Conference on Structure Design of Asphalt Pavements, 1, 550–561.
- Chabot, A., Chupin, O., Deloffre, L., Duhamel, D., 2010. ViscoRoute 2.0. A Tool for the Simulation of Moving Load Effects on Asphalt Pavement. Road Materials and Pavement Design 11, pp. 227-250. 10.1080/14680629.2010.9690274
- De Beer, M., Maina, J.W., van Rensburg, Y., Greben, J., 2011. Towards Using Tire-Road Contact Stresses in Pavement Design and Analysis.
- Duong, Ngoc Son., Blanc, J., Hornych, P., Bouveret, B., Carroget, J., & Lefevre, Y., 2019. Continuous strain monitoring of an instrumented pavement section, International Journal of Pavement Engineering, 20:12, 1435-1450, DOI:10.1080/10298436.2018.1432859
- Grellet, D., Doré, G., Chupin, O., Piau, J.-M., 2018. Highlighting of the viscoelastic behaviour of interfaces in asphalt pavements – a possible origin to top-down cracking. Road Materials and Pavement Design 19, 581–590. <https://doi.org/10.1080/14680629.2018.1418721>
- Hornych, P., Kerzreho, J. P., Chabot, A., Bodin, D., Balay, J. M., Deloffre L., 2008. In Pavement Cracking - Al-Qadi, Scarpas & Loizos (eds). The LCPC's ALT facility contribution to pavement cracking knowledge. <https://doi.org/10.13140/2.1.2361.9529>
- Huet, C., 1963. Etude par une méthode d'impédance du comportement viscoélastiques des matériaux hydrocarbonnés (PhD thesis). Université de Paris.
- Nguyen, M. L., Chupin, O., Blanc, J., Piau, J.-M., Hornych, P., Lefevre, Y., 2020b. Investigation of Crack Propagation in Asphalt Pavement Based on APT Result and LEFM Analysis. Journal of Testing and Evaluation, 48(1), 20180933. <https://doi.org/10.1520/JTE20180933>
- Sayegh, G., 1965. Variation des modules de quelques bitumes purs et bétons bitumineux, Thèse de Doctorat d'Ingénieur. Faculté des Sciences de l'université de Paris.
- Wang, H., Al-Qadi, I., 2010. Evaluation of Surface-Related Pavement Damage due to TireBraking, Road Materials and Pavement Design, 11:1, 101-121, DOI: 10.1080/14680629.2010.9690262