Strain Measurement in Pavements with a Fibre Optics Sensor Enabled Geotextile

Olivier Artières[1], Matteo Bacchi[2], Paolo Bianchini[1], Pierre Hornych[3] and Gerrit Dortland[1]

[1]TenCate Geosynthetics France, Italy and The Netherlands
[2]Impresa Bacchi, Italy
[3]IFSTTAR, France

Abstract. A new sensing solution based on the combination of a technical geotextile and fibre optics measurement technologies has been developed for strain and temperature measurement in pavement. This monitoring system has been evaluated in the laboratory with a 4-points fatigue device. Our results show a very high sensitiveness of the sensor enabled geotextile to be able to detect strain smaller than 10 micro-strain and fast dynamic movements with frequencies up to 1000 Hz. Installation trials have been carried out in different locations with conventional road paving equipment, in both asphalt and concrete pavement applications. The response of this sensing solution to traffic loads is very good and makes of this technology a powerful tool for road ageing assessment, analysis and maintenance.

Introduction

A lot of work has been done in the past years to understand the ageing process of road pavements and to develop solutions to decrease or eliminate cracks and structural deformations due to traffic and climatic fatigue. A very common solution is the use of technical paving textiles both to reinforce the base of the overlays and create a watertight continuous bituminous liner to avoid water penetration deep into the structure. However, even if these solutions are effective in increasing the lifetime of the structure, there remain big issues for roads designers, contractors and owners such as:

1. Evaluating the in-situ performance of the structure.
2. Selecting the best techniques depending on the road’s subsoil and structure.
3. Assessing the actual ageing of the pavement.

4. Predicting the period and the scale of maintenance operations.

Monitoring of road pavements is not easy as the environment is very aggressive for the sensors: hot temperature and high compaction stresses. Classical techniques use electro-mechanical sensors. The rate of damage of these sensors is very high: it is common to lose 20 to 50% of the sensors installed just after the compaction process. Also these sensors are big compared to the size of the cracks they aim to monitor which creates scale and border effects detrimental to their detection capabilities.

This paper presents a new sensing solution based on the combination of a technical geotextile and fibre optics measurement technologies that has been developed for strain and temperature measurement in pavement. After introducing the principles of this sensing solution, its performance both in laboratory and in scale 1:1 real conditions are described.

The Monitoring Solution Based on the Fibre Optics Sensor Enabled Geotextile

Fibre optics have been widely used for many years in civil engineering applications, specialty pipelines, structural health monitoring systems and hydraulic works applications such as concrete and earth dams, levees and dikes.

By embedding optical fibres onto a geotextile fabric (Figure 1), TenCate GeoDetect® is an innovative sensor enabled geotextile that enhances the performance of the fibre optics sensors when applied in contact with soil, concrete or asphalt: the geotextile fabric creates an excellent anchoring interface with the surrounding media. With the geotextile being securely anchored in the asphalt or concrete, and the strong connection between the optical fibre and the geotextile, even very small soil strains can be detected. This friction interface also facilitates the transfer of movements from the geotextile to the fibre optic line. Moreover, and when necessary, high tensile stiffness and reinforcement properties can be included to the sensor enabled geotextile.

Different fibre optic sensing technologies can be embedded, such as Fibre Bragg Gratings which measures very narrow optical index changes written at given locations inside the optical fibre line for point specific measurements, or Brillouin and Raman technologies which provide distributed measurements at any point along the optical fibre up to 50 kilometres in length. Fibre optic sensing technologies are able to measure very precisely parameters such as temperature or strain under static or dynamic conditions.

The monitoring solution includes the fibre optics sensor enabledgeotextile, the instrumentation equipment and data acquisition software (Figure 1). Different

monitoring strategies may be incorporated into the design. Either periodic or continuous monitoring can be used as an early warning system.
In comparison to existing monitoring systems made of numerous individually wired sensors, the fibre optic solution measures continuously hundreds of points along the full length of the structure with a single instrumentation configuration. It can provide deformation location with a spatial resolution of less than 0.5 m in some cases. Once installed, the sensor enabled geotextile communicates the strain and temperature data to the system's instrumentation equipment. Strain as low as 0.02% can be measured, and with the proper software, changes in temperature can be monitored at 0.1°C. The optical sensing technology requires no sensor calibration prior to the measurement; temperature compensation may be necessary for amplitudes higher than 10°C.

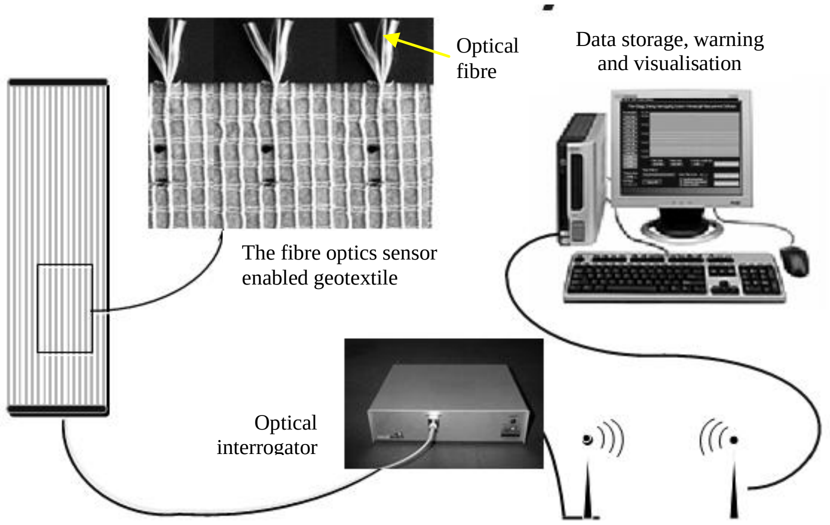


Figure 1. The TenCate GeoDetect® system components

Laboratory Tests

Preliminary trials have been carried out at the Impresa Bacchi laboratory in Carpiano, Italy, to check the resistance of the sensor enabled geotextile to hot temperature, to monitor the stresses due to the compaction of the bituminous concreteand assess its sensitiveness in measuring strain in a concrete asphalt layer.

Preparation of the Specimen

Specimen asphalt beams were built into a box 40 cm x 30 cm, with the following layers from the top to the bottom: 3 cm layer of bituminous concrete, the sensor enabled geotextile impregnated with a bituminous emulsion, 3 cm layer of bituminous concrete (Figure 2), and compacted.

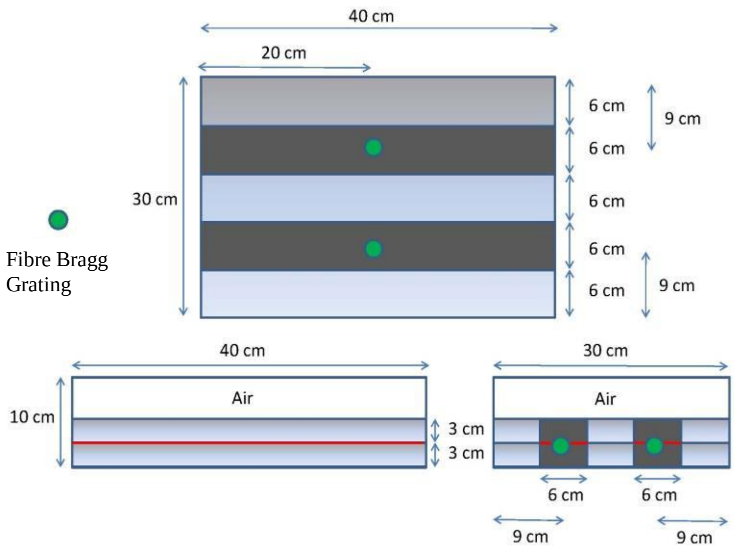


Figure 2. Top view (above) and cross-section of the concrete asphalt blocks preparation, each producing two specimen beams with one strip of sensor enabled geotextile (red) embedding one optical line and one Fibre Bragg Grating in the middle of the beam.

Figure 3. Compaction of the second layer of bituminous concrete.

To create the beams we used a Dyna-Comp, pneumatic roller compactor with a maximum vertical force of 30 kN (Figure 3). The roller compactor provides a pneumatically powered means of compacting slabs of asphaltic material in the

laboratory under conditions, which simulate in-situ compaction. Slabs produced measured 300 mm by 400 mm and 50 mm thick.
The precise depth of a slab can be preset enabling the user to compact a certain mass of material to a selected volume thus providing a target mix density. Several compaction cycles were tested with about 3 passes for each to achieve normal compaction strength. Different levels of vertical force can be selected up to approximately 30 kN. As the width of the roller is 300 mm, the compactioneffort of the largest static site roller can be reproduced. The strongest cycle started with 3 kN, then 5 kN, then 10 kN, then 19 kN.

The sensors reacted very well to the different passes which are clearly visible from the strain measurements. The maximum strain measured was about 1,3 % (Figure 4). From these blocks are cut 2 beams. A total of 8 beams were produced. Each of them included a 40 cm x 15 cm sensor strip, embedded with one optical fibre line which contained one Fibre Brag Grating in the middle (Figure 2). The first part of the experiment shows the resistance of the sensor to the installation, compaction stresses and to hot asphalt temperature. The temperature of the bituminous concrete was 140°C during placement on the sensor enabled geotextile strip. No damage was observed on the optical fibre or on the FBG during the placement.

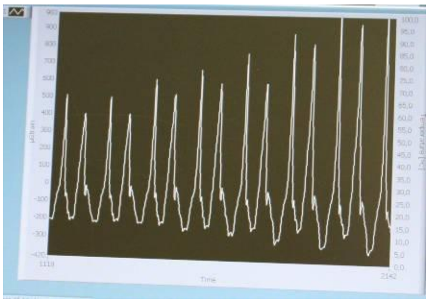


Figure 4. The strain curve measured during compaction with an increasing strength. The peaks corresponding to the passes are visible.

Tests with the Bending Machine

The beams were tested into a 4 points “Nottingham” bending test machine (Figure 5). The model is an IPC Global UTM - 25 based on a 25 kN capacity hydraulically-driven load-frame equipped with the 4 Point Bend Apparatus, a stand-alone system for four-point fatigue life testing of asphalt beams subjected to repeated flexural bending. The cradle mechanism allows for backlash free rotation and horizontal translation of all load and reaction points. Pneumatic actuators at either end of the cradle centre the beam laterally and clamp it. Servo-motor driven clamps secure the beam at four points with a pre-determined clamping force. Haversine loading is applied to the beam via the built-in digital servo-controlled pneumatic actuator.

In our case we tested the beam with several loading curve (Sinusoidal, haversine, triangular, rectangular, etc).

A total of 4 beams were tested. The sensor strips were connected to a FBG interrogator with a dynamic acquisition frequency from 1 to 100 Hz, depending on the fatigue cycle chosen. As a result, all cycles were accurately measured with the sensor enabled geotextile , even when very low vertical amplitude of 10 µstrain was applied (Figure 5). For each beam, at the end of the loading cycles, a pseudo-static normal loading was applied to reach a deflection of 1 cm in the middle of the beam: the corresponding 0.2% horizontal strain was measured by the sensor.

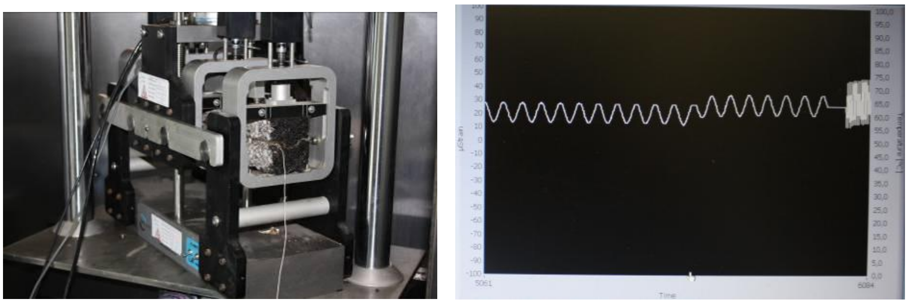


Figure 5. The specimen beam inside the four points bending machine (left) and the strain curve resulting of sinusoidal bending cycles producing strain variation of 10 micro strains amplitude (right).

In-situ Trials

The IFSTTAR Accelerated Pavement Test facility

After these laboratory evaluations, a scale 1:1 test sections was built with an asphalt pavement and monitored with the fibre optics sensor enabled geotextile. It was installed in the fatigue carousel at IFSTTAR (LCPC) in Nantes (Figure 6).

Figure 6. The IFSTTAR Accelerated Pavement Test facility

This Accelerated Pavement Test facility was built for the study of full scale experimental pavements submitted to heavy traffic levels. This major facility became operational in 1984. It makes it possible to reproduce in less than a week up to a full year's truck traffic load supported by a heavily trafficked pavement, with load speeds capable of reaching 100 km/hr. The site comprises three 110-m long rings with an average radius of 17.50 m and a width of 6 m. It is possible to position the loads at different radii of rotation depending on the arm length. The loads may be adjusted between 45 kN on a single wheel and 135 kN on either a three-axle configuration with single wheels or a double axle with two wheels each. The facility experimental site consists in three test rings, with its central motorization and four arms being movable from one ring to another. Further description is given in [1, 2].

Tested Structure and Installation of the Sensor Enabled Geotextile

Two sensor enabled geotextile strips have been installed bellow a 8 cm thick asphalt concrete layer with classical road construction equipment (Figure 7). One strip is installed in the direction of the traffic, the second strip is installed perpendicular to the road. This second strip embedded one optical line with three FBGs spaced 1 m apart along the line. The sensors were monitored before, during and after installation. No damage was observed during this operation. Installation creates the highest stress, between 600 and 2000 µstrain, part of it due to temperature increase (Figure 8). A slow relaxation of the strain values have been observed since the completion of the test.

Results

The first measurements took place 4 months after the installation on June 16, 2011. The configuration of the 4 arms was the following: three arms were equipped with single axles with dual wheels (12.00 R 20.0 tires), loaded at 50 kN, and the fourth arm was equipped with a single axle with a super single wheel, (455/55 R22.5 tire) also loaded at 50 kN.

Figure 7. Pouring asphalt concrete on top of the sensor enabled geotextile strips (left) and compaction (right)

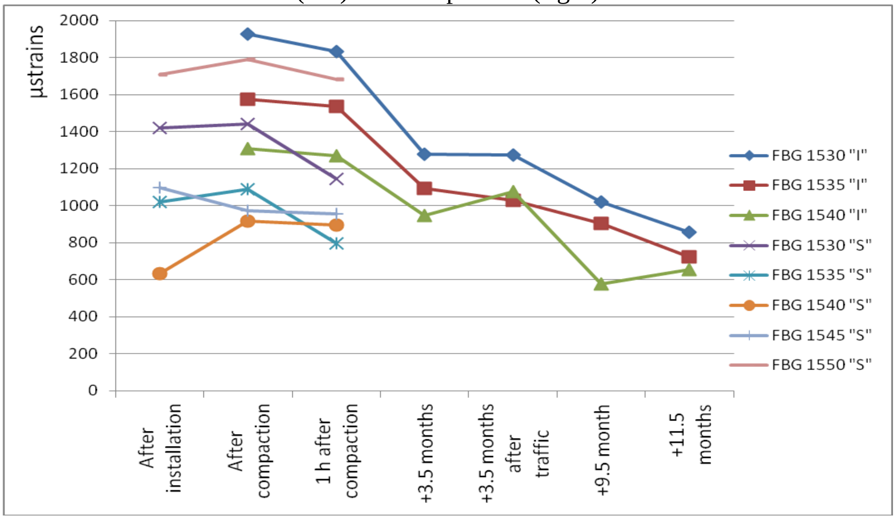


Figure 8. Relative strain measured by the Fibre Bragg Gratings during and after installation in the asphalt pavement. Zero value: just before installation.

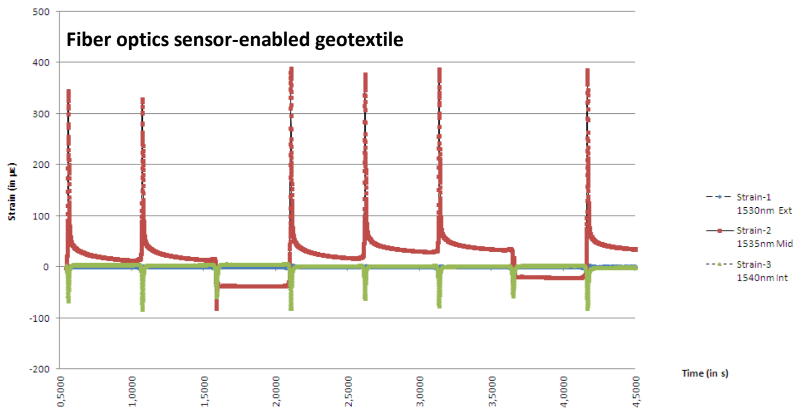
The response of the fibre optics sensors was measured for 11 different lateral positions of the wheels, spaced 105 mm apart. The tests were made at a loading speed of 40 km/h, and an average pavement temperature of 28°C. Figure 9 shows an example of the strain measured by one sensor enabled geotextile strip for the position n°8, where the dual wheels pass near the centre of the wheel path. We can observe that mainly one FBG is strained (n°2), the FBG n°3 measuring some small negative strain (contraction). The strain measured depends on the type of wheel load. The dual wheels produce a maximum positive transverse strain (in extension) close to 400 µstrain. The single wheel produces a small negative strain, indicating that the wheel is not passing exactly on top of the sensor.

In comparison, figure 9 shows the response of a strain gage, used as classical instrumentation on the test track to measure strains in asphalt layers. Again, the figure shows the transverse strains under the passage of the 4 rolling wheels, for position 8. Under the dual wheels, the maximum transverse strain level is 300 µstrain.

Even if strain gage and FBG are both local measurements, it is difficult to compare their measured strain values directly: strain gages measure a local strain under a given position of the wheel (over a length of about 10 cm), while the geotextile may transfer a part of strain to the optical fibre, which can react even if the load is not applied on top. However, it can be seen that the quality of the signal is satisfactory (Figure 10), and that the shape and amplitude is similar to the strain gage response (Figure 11). Figure 10 also shows that measurements made at different ageing times of the pavement are consistent. But further work is necessary to define how the signal could be interpreted, to obtain meaningful strain values.

Conclusion

The fibre optics sensor enabled geotextile has proven to be a good monitoring system to measure strain into concrete asphalt road pavements. By adopting specific installation procedures, its survivability to installation stresses, high temperature and compaction, is very good compared to other sensor devices. It can be applied directly during the road construction thus measuring the real state of the road. The sensitiveness measured both in laboratory and on site are a few micro-strains. The sensor requires no calibration after installation that makes it very easy to handle. This sensor technology has been measuring for more than one year different pavement structures in the field which makes it very reliable for mid and long term maintenance data acquisition, even on damaged areas up to 5% strain.



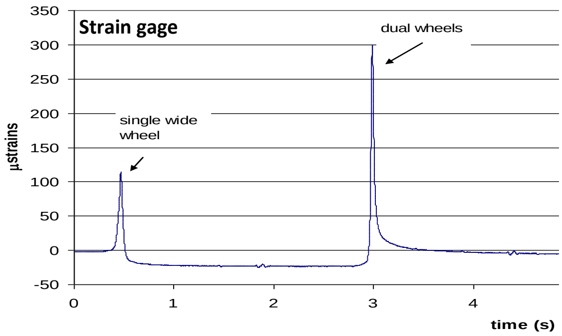


Figure 9. Comparison of the transverse strain measured at the base of the bituminous layer under the 4 rolling wheels with the fibre optics sensor enabled geotextile (+3.5 months) and strain gages

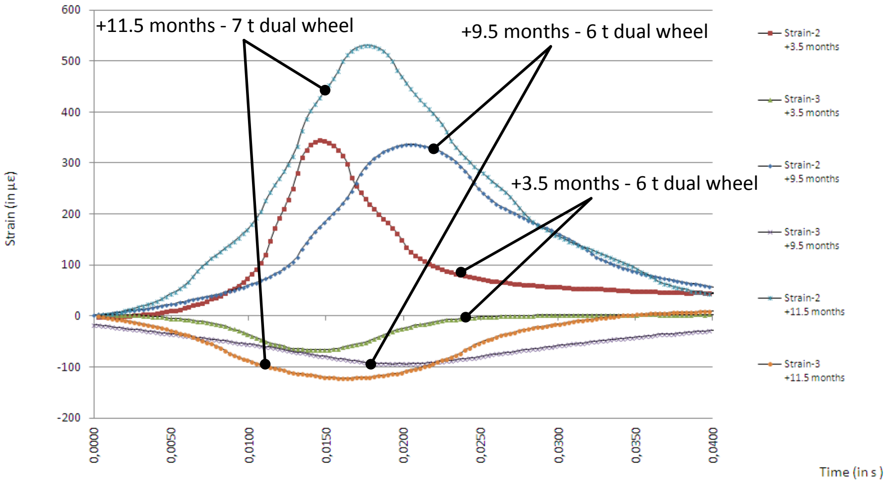


Figure 10. Strain curves measured with the fibre optics sensor enabled geotextile resp. +3.5, + 9.5 and 11.5 months after installation.

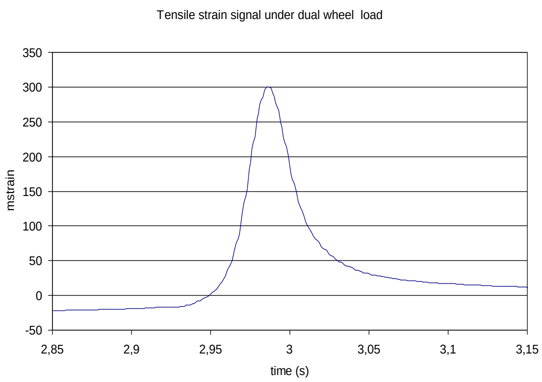


Figure 11. Strain curve measured with strain gages

References

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