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Demonstrating Innovative Technologies for the Flemish Asphalt Sector in the CyPaTs Project

Wim Van den Bergh 1, Geert Jacobs 1, Patricia Kara De Maeijer 1, Cedric Vuye 1, Sravani Arimilli 1, Karolien Couscheir 1, Leen Lauriks 1, Robin Baetens 1, Ian Severins 1, Alexandros Margaritis 1, Navid Hasheminejad 1, Johan Blom 1, Jan Stoop 1, Muddsair Sharif 2

1 EMIB research group, Faculty of Applied Engineering, University of Antwerp, 2020 Antwerp, Belgium
2 Imec IDLab research group, Faculty of Applied Engineering, University of Antwerp, 2020 Antwerp, Belgium

patricija.karademaeijer@uantwerpen.be

Abstract. In 2015, the ROAD IT project initiated the development and demonstration of an integrated and coherent IT process control system for the Flemish asphalt sector in order to modernize existing asphalt paving technologies and to obtain real-time data to monitor pavement behavior. One of the demonstration test tracks is CyPaTs, the construction of a bicycle path built in September 2017, using innovative technologies (www.uantwerpen.be/cypats). Five technologies are described in this contribution. An asphalt solar collector (PSC) with a piping system was installed directly in the asphalt. Cold water during summer season and hot water in winter season running through the pipes, keep the asphalt structure in a better temperature interval, avoiding rutting and cracking. Other advantages of this system are: energy gain, the prevention of damage to asphalt and the enhancement of traffic safety. The expected energy gain per year varies between 0.5 and 0.8 GJ/m². About 20% of this energy is used for the operation of the asphalt collector itself. The remaining 80% can be used in nearby buildings. Fiber Bragg Grating (FBG) monitoring system was integrated in all three asphalt layers for the first time in Belgium. Two novel approaches of FBGs installation in asphalt layers were elaborated in this bicycle path: installation of FBGs in prefabricated asphalt specimens at the bottom of base layer and installation of FBGs in a saw cut of approx. 2mm in the previously constructed asphalt layer. The results proved a survival rate of the FBGs of 100%. The obtained strain and temperature data from FBG monitoring system has proved to be an excellent approach to establish and reflect the real condition of the asphalt pavement behaviour in time at different temperatures. The temperatures of the asphalt pavement during construction were followed up by the infrared thermography measurement techniques: a thermographic line-scanner (PAVE-IR by Moba AG) which was mounted at the back of the finisher and a hand-held IR camera (FLIR T640) was used for taking pictures every 2 meters. A real-time temperature contour plot of the pavement during construction was created to monitor asphalt pavement temperatures for quality inspection during the paving process or for later assessment. Two other non-destructive technologies for quality assessment were applied during this project. At first, the thickness was measured using aluminium plates and the MIT-SCAN T3. The obtained values were compared with topographic height measurements. Secondly, the density was measured with the PQI-380 non-nuclear density meter at several spots. The objective here is to check the density of the bicycle path, as well as the accuracy and investigate different parameters that influence the variations of the results, in particular the temperature dependency.
1. Introduction
In most sectors, IT is successfully implemented to optimize and control processes. These real-time applications provide improved process management. In the asphalt sector, however, does it really happen? In 2015, the ROAD_IT project (https://www.uantwerpen.be/en/research-groups/emib/projects-publications/road-engineering/road-it/) initiated the development and demonstration of an integrated and coherent IT process control systems for the Flemish asphalt sector in order to modernize existing asphalt paving technologies, obtain real-time data to process control and monitor pavement behaviour, and generate data storage for use in future e.g. optimization of material use for reclaiming.

In September 2017, CyPaTs bicycle path was constructed in front of the Applied Engineering Faculty in the Campus Groenenborger at University of Antwerp (www.uantwerpen.be/cypats). It’s a unique project, because of two reasons: first, several new technologies were demonstrated for the road construction sector, and second, it allows several projects to be continued by our researchers for a long time after the construction. It is also a demonstration project for the entire road construction sector. Five innovative technologies were implemented in the CyPaTs bicycle path which are described in this paper.

2. Innovative technologies

2.1. Pavement solar collector
Asphalt concrete road surfaces absorb significant amounts of solar radiation, up to 40 MJ/m² over the course of a day during summer, which causes high temperatures in the pavement structure [1]. This heat energy can be harvested using a heat exchanger system embedded in the pavement structure, e.g. a heat exchanging asphalt layer (HEAL) system. A HEAL-system consists of a pavement solar collector (PSC), a heat exchanger and a heat storage. Cold water during summer season and hot water in winter season running through the pipes, keep the asphalt structure in a better temperature interval, avoiding rutting, cracking and ravelling. Other advantages of this system are: energy gain, the prevention of damage to asphalt and the enhancement of traffic safety. An increased traffic safety can be guaranteed by prevention of damage by keeping the pavement ice-free during frost days. The expected energy gain per year varies between 0.5 and 0.8 GJ/m². About 20% of this energy is used for the operation of the asphalt collector itself. The remaining 80% can be used in nearby buildings.

![Figure 1. Installation of pavement solar collector in CyPaTs bicycle path (UAntwerpen)](image-url)
Since there are many variables that have to be taken into account when designing a HEAL-system, research is being done at three different levels: prototype, Finite Element Model and validation of the FEM model. A large-scale prototype (with dimensions (approx. 30m² (8.5mx3,5m)) was designed and installed directly in the asphalt in CyPaTs bicycle path (see figures 1&2). The geometry of the PSC consists of a number of horizontal pavement layers, one of which contains at least one pipe loop that acts as a heat exchanger. The entire PSC is modelled in 3D using finite element techniques. In this model PSC is simulated using the heat transfer in solids module and CFD2 module in the COMSOL Multiphysics software. The development of a modelling framework and its validation with a self-instructed laboratory experiments is currently carried out [2].

Figure 2. IR camera image of installed pavement solar collector in CyPaTs bicycle path

2.2. Fiber Bragg Grating (FBG) monitoring system

The monitoring of the pavement is an essential part of pavement research and plays an important role in the transportation system, e.g. weigh-in-motion systems and – upcoming technology – fiber Bragg grating (FBG) for the monitoring of the deformation and ageing process. This FBG based sensors technique is one of the most used and well-known technologies in commercial applications in the field of optical communication and composite materials. However, it is not commonly used in asphalt technology due to its application restrictions during rough construction processes, which require the sensors to endure high temperatures (up to 160°C), moisture, high compaction force, repeated heavy loading, etc. These days, the development of real-time monitoring systems with FBG sensors installed in pavement has a high interest for research of the pavement behaviour. The accurate measurement of the pavement responses (strain and stress) distributions in pavement structure, combined with temperature, is critical for the understanding of pavement behaviour and the modelling of pavement failure [3].

FBG monitoring system was integrated in all three asphalt layers for the first time in Belgium in CyPaTs bicycle path at UAntwerpen (see figure 3). Two novel approaches of FBGs installation in asphalt layers with cross-section configuration were elaborated in CyPaTs bicycle path: installation of FBGs in prefabricated asphalt specimens at the bottom of the base layer and the installation of FBGs in a saw cut of approx. 2mm in the previously constructed asphalt layer [4]. The results proved a survival rate of the FBGs of 100%.
It was observed that fibers in the transverse direction are mostly under compression and in the longitudinal direction – under tension; the response of the sensors at the first day after paving showed a higher shift than 28 days later. The difference of the recorded strain values depended on measurement time period after paving and temperature. The obtained strain and temperature data from FBG monitoring system has proved to be an excellent approach to establish and reflect the real condition of the asphalt pavement behaviour in time at different temperatures [5].

Figure 3. Installation of FBG sensors in three asphalt layers in CyPaTs bicycle path (left: in prefabricated asphalt specimens; right: placed in grooves)

2.3. Thermographic line-scanner

Infrared thermography as a tool for non-destructive analysis can be used in asphalt road engineering to register asphalt temperatures [6-8] and to identify areas of thermal segregation. There are two main concerns for application of hand-held IR cameras:

i. interpretation of the data, difference between the readings of surface temperatures and the actual core temperatures, and

ii. applicability on the construction site when camera has to be moved often and placed in a safe zone next to the paved road.

A more recently developed paving equipment feature is the infrared line-scanner, which is mounted on top of the finisher and creates a real-time temperature contour plot of the pavement during construction [9].

In CyPaTs project, the temperatures of the asphalt pavement during construction were followed up by the infrared thermography measurement techniques: a thermographic line-scanner (PAVE-IR by Moba AG) which was mounted at the back of the finisher and a hand-held IR camera (FLIR T640) was used for taking pictures every 2 meters. A real-time temperature contour plot of the pavement during construction was created to monitor asphalt pavement temperatures for quality inspection during the paving process or for later assessment. In order to obtain derivation from the surface temperatures when IR radiation intensity is measured, three groups of parameters should be considered and set correctly in the camera software:
1. The radiation measured by the camera, travels through the atmosphere in between the camera and the measured target. The distance, air temperature and relative humidity are monitored to account for transmission losses through this atmosphere. These conditions are measured at the start and the beginning of the pavement construction, for each day consecutively.

2. The radiation measured by the camera, can originate from the emitted radiation of the object itself or from the reflected radiation from the environment. The parameter defining the ratio between both, is the emissivity of the material surface. The emissivity of the asphalt paving material ($\varepsilon=0,96$) was retrieved from the ECOSTRESS spectral library information [10-11] within the spectral range of the IR camera.

3. The reflected apparent temperature can be measured to compensate for the reflected radiation from the environment. The result depends on the viewing angle as well as the environment itself, which both vary constantly during the pavement construction. Each consecutive day, two extremes of reflected apparent temperature were measured. The open sky is the coldest possible reflected apparent temperature, while the environment including the roller, workers, buildings, etc. is the warmest possible reflected apparent temperature.

In figure 4 it can be seen the results of the hand-held IR camera when finisher paused around the 86m marker of the bicycle path during the pavement construction process. The temperature difference before (“Li2 average”) and after (“Li1 average”) the finisher stop is 59,1°C. The influence of the air temperature, relative humidity and object distance on the resulting temperature difference was negligible. The influence of the reflected apparent temperature however was found to be relevant. The temperature difference between the averages variates from 58,8°C until 59,4°C. The influence on the temperature difference between the maximum (on “Li1”) and minimum (on “Li2”) temperatures is even larger. The nominal temperatures itself are also influenced by up to 4°C. The reflected apparent temperature cannot be measured accurately during pavement construction. As a result, the variation on the temperatures is an integral part of the interpretation of the infrared measurements. An extra margin can be advised, whenever these measurements would be used for compaction control.

![Figure 4. Hand-held IR camera image showing finisher stop around 86m on CyPaTs bicycle path](image-url)
Chyba! Nenašiel sa žiaden zdroj odkazov. shows the thermographic line-scanner readings in the corresponding area. The readings are averaged on squares of 25 by 25 cm. The overall appearance of the two thermographic techniques seems quite similar. Moreover, also the mean values of the two lines (indicated in red) correspond to the ones selected in figure 4 within a tolerance of 3°C. These tolerances can be partially explained by the time difference between the readings by the two techniques. Because the line-scanner reading happens approximately 1.5m behind the screed (which can be derived from the length of the colder area after a paver stop), there is a time difference between the indicated readings of the line-scanner and the moment the image in figure 4 was taken.

![Figure 5. IR line-scanner mapping showing finisher stop around 86m on CyPaTs bicycle path](image)

It can be concluded that paver stop can be interpreted differently by applying each technique depending on how the data are captured. While the IR camera picture shows only one linear area with large temperature differences (the place of the screed at the moment of the finisher stop), the thermographic line-scanner shows two: the location of the screed and the location of the temperature readings at the moment of the finisher stop. Both techniques are suitable to monitor asphalt pavement temperatures during construction, but the line scanner is preferred because of the constant data supply during finisher movement, while the hand-held IR camera needs to be operated manually and provides only instantaneous pictures that need further processing before they can be useful during construction.

2.4. Non-destructive technologies for quality assessment

The density of an asphalt mix is one of the most influential parameters considering road quality and hence durability [12]. Reaching a certain aimed density, together with the aimed layer thickness, leads to the requested mix characteristics namely stiffness, fatigue properties, resistance against permanent deformation and water sensitivity [13]. To determine the layer thickness and density, traditionally cores are drilled, leading to local pavement damage. This causes increased risk deterioration and damage extension, unsafe situations and shortening of service life. Additionally, the information derived from the cores is derived after the work is completed, which is too late to anticipate.

Therefore, there is a need for a real-time and non-destructive measurement of the layer thickness and density during the compaction phase which allows to adjust the rolling process on site. In CyPaTs project, the thickness of an asphalt layer was measured using aluminium plates and the MIT-SCAN T3, and density using the PQI-380 non-nuclear density meter (see figure 6). The objective was to check the
density of the asphalt of bicycle path, as well as the accuracy and investigate different parameters that influence the variations of the results, in particular the temperature dependency.

![Image](image1.png)

**Figure 6.** Measurement campaign with MIT-SCAN-T3 (left) and PQI-380 (right) during construction of CyPaTs bicycle path

2.4.1. *Aluminium plates.* The obtained values from the measurements using aluminium plates and the MIT-SCAN T3 were compared with topographic height measurements. The data for this study was obtained from a selection of points presented in Figure and Figure , the main results are presented in table 1.

![Image](image2.png)

**Figure 7.** Measuring points of layer thickness

![Image](image3.png)

**Figure 8.** Cross section of the pavement and the positioning of the aluminium plates

The surface of the base was uneven leading to a larger standard deviation in layer thickness in the base layer (14 mm) compared to the middle- and the top layer (4 mm) (measured topographically). The values of M (the layer thickness measured by MIT-SCAN-T3) are in each case higher than the values of T (layer thickness measured by topographic height measurements). For the plates on the base layer, the difference between M and T enlarges only 1 mm if the layer thickness of the top layer is added to the layer thickness of the middle layer. The average difference between M and T over the 20 measurements is 6 mm and 8%, which is too high to indicate an accurate measuring technique. The standard deviation of the difference between M and T over the 20 measurements is 4 mm and 6%.
Table 1. Results of layer thicknesses

| Measuring Point | M | T | V (%) | M | T | V (%) | M | T | V (%) | M | T | V (%) |
|-----------------|---|---|-------|---|---|-------|---|---|-------|---|---|-------|
| Base Layer      | 4.9 | 3.6 | 1.3  | 27 | 13 | 12 | 1.3 | 11 | 0.2 |
| Middle Layer    | 6.6 | 5.7 | 0.9  | 14 | 15 | 14 | 1.2 | 8  | 0.3 |
| Top Layer       | 6.8 | 6.7 | 0.1  | 1 | 15 | 14 | 1.2 | 8  | 1.1 |
| Middle + Top    | 6.9 | 6.4 | 0.5  | 7 | 15 | 14 | 0.8 | 6  | 0.3 |
| Average         | 6.3 | 5.6 | 0.7  | 12 | 14.4 | 13.3 | 1.2 | 8  | 0.5 |
| Std. Dev.       | 0.9 | 1.4 | 0.5  | 11 | 0.8 | 1.0 | 0.3 | 2  | 0.4 |

2.4.2. PQI-380 non-nuclear density meter. In order to evaluate the homogeneity of the asphalt layer, the density was measured with the PQI-380 non-nuclear density meter at 6 predefined points for base and binder asphalt layers and at 11 points for the top asphalt layer. To investigate the parameters that influence the measurements and can cause variations, density measurements were collected from 1 point per layer every minute for 2 hours throughout the cooling process and sporadically the following hours. The derivative percentage of air voids is presented in Figure 11.

All results are within the valid limits of 1% and 10%, as expected by the Flemish Standards (Standaardbestek 250 v 4.0) [14]. However, there are no regulations for homogeneity. The results in Chyba! Nenašiel sa žiaden zdroj odkazov. show that in percentage air voids cannot be explained to variations in temperature but should be related to other variables.

Figure 9. % air voids base layer

Figure 10. % air voids middle layer

Each measurement has been executed 10 times to evaluate the repeatability of the test. Fifty percent of the PQI measurements had a standard deviation less than 0.3 % air voids which is acceptable (see figure 13). The influence of the surface temperature of the asphalt on the required offset is very limited. It is, therefore, possible to have differences in surface temperature between offset-measurements and actual measurements.
3. Conclusions
For decades, pavements were designed based on empirical relationships reflective of limited conditions. Current specifications do not allow innovations and that makes it difficult to bring innovative technologies into standard application in the asphalt industry. Development of long life pavements requires innovative designs, materials and construction followed by monitoring of pavement condition to evaluate short- and long-term performance. Today, the necessity to build roads in a smart way is in a high demand: the ability to account for unique site conditions, real-time asphalt pavement structure behaviour and material variations to obtain durable, long-lasting pavement by implementation of innovative technologies, which increase life of pavements and decrease annual maintenance costs.

The main conclusion of this study and project realization is that these implemented innovative technologies in a CyPaTs bicycle path (UAntwerpen) showed necessity to improve pavement quality to a sustainable level during construction but also for the use during service as a part of the pavement management system. It has been observed that two the most promising technologies are FBG and IR line scanner. Non-destructive technologies for quality assessment - PQI and aluminium plates - have to be improved, and PSC requires further monitoring.

Within the CyPaTs project it was clearly underlined that the more we know about: asphalt paving process, application of intelligent compaction, determination of real-time pavement density, asphalt pavement real-time behaviour, the closer we are to the concept of intelligent pavement design based on real-time data.

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