IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

The use of a non-nuclear density gauge for monitoring the compaction process of asphalt pavement

To cite this article: Wim Van den bergh *et al* 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* **236** 012014

IOP Conf. Series: Materials Science and Engineering **236** (2017) 012014 doi:10.1088/1757-899X/236/1/012014

The use of a non-nuclear density gauge for monitoring the compaction process of asphalt pavement

Wim Van den bergh[1], Cedric Vuye[1], Patricia Kara[1], Karolien Couscheir[1], Johan Blom[1] and Philippe Van Bouwel[2]

[1]University of Antwerp, Faculty of Applied Engineering, EMIB research group, 171 Groenenborgerlaan, Antwerp 2020, Belgium
[2]Infrastructure & Real Estate, Brussels Airport Company, 1C Luchthaven Brussel Nationaal, Zaventem 1930, Belgium

E-mail: wim.vandenbergh@uantwerpen.be

Abstract. The mechanical performance of an asphalt pavement affects its durability – thus carbon footprint. Many parameters contribute to the success of a durable asphalt mix, e.g. material selection, an accurate mix and even the road design in which the asphalt mix quality is quantified. The quality of the asphalt mix, by its mechanical properties, is also related to the compaction degree. However, and specifically for high volume rates, the laying process at the construction site needs an effective method to monitor and adjust immediately the compaction quality before cooling and without damaging the layer, which is now absent. In this paper the use of a non-nuclear density gauge (PQI – Pavement Quality Indicator) is evaluated, based on a site at Brussels Airport. Considering the outcome of the present research, this PQI is advised as a unique tool for continuous density measurements and allow immediate adjustments during compaction, and decreases the number of core drilling for quality control, and as a posteriori asphalt pavement density test where cores are prohibited. The use of PQI could be recommended to be a part of the standard quality control process in the Flemish region.

1. Introduction

Asphalt pavement material is a part of the high-carbon emission model [1]. The International Energy Agency (IEA) reported that CO_2 emissions from the transport industry account for approximately 27.8% of global emissions [2]. The quality of the pavement surface affects the use of energy and safety. The mechanical performance of an asphalt pavement affects its durability – thus even enlarges carbon footprint. Hence, increasing the quality of an asphalt pavement leads to beneficial improvements towards a reduction of the carbon footprint. In order to avoid a high carbon footprint, as mentioned in [1], the use of asphalt should be optimized by quality and performance increase and recycling technologies. Many parameters contribute to the success of a durable asphalt mix, e.g. material selection, an accurate mix and even the road design in which the asphalt mix quality is quantified. The quality of the asphalt mix, by its mechanical properties, is also related to the compaction degree. Asphalt technologists agree that the density of an asphalt mix is one of the most prominent measures for road quality [3-5]. Reaching a certain desired density optimizes the desired mix characteristics, like: stiffness, fatigue characteristics, resistance against permanent deformation and moisture [4]. Poor density can lead to settlements in a later stage with a shorter life span of the

IOP Conf. Series: Materials Science and Engineering **236** (2017) 012014 doi:10.1088/1757-899X/236/1/012014

pavement as a result, because rutting will occur in the wheel tracks. Therefore, good compaction is very important. Currently, this problem occurs more frequently: there is less time available to construct the road, many new asphalt mixes are introduced, often work is planned outside the ideal paving season and as a result, work is undertaken in less than ideal weather conditions and circumstances. So, reaching the desired quality during the compaction process is under threat, which often makes the result more and more uncertain [6]. In Belgium a project called 'intelligent compactors' was worked out using IT systems on different types of compaction rollers. No real practical procedure is worked out, so far, but the level of compacting is agreed to be crucial for the service life and performance. Other more practical methods are searched for quality control.

Key problem within the asphalt paving process is the lack of knowledge about the ongoing process of compaction: determining the level of compaction and if an additional compaction is needed; specifically for high volume rates and avoiding a high number of core drillings for controlling the compaction process where cores are prohibited, or repaving is not permitted due to limited closure of the pavement, for example, at the airport. Airport pavements are constructed to provide adequate support for the loads imposed by airplanes and to produce a firm, stable, smooth, all-year, all-weather surface free of debris or other particles such as loose stones from raveling that may be blown or picked up by propeller wash or jet blast. To produce such pavements requires a coordination of many factors of design, construction, and inspection to assure the best possible combination of available materials and monitoring the compaction of the pavement. Considering this, core drilling is strictly prohibited at those pavements as it weakens the paved layer locally, thus contributes to a higher risk for damaging the layer, resulting in a decreased service life or water infiltration problems, e.g. on bridges. Therefore, the laying process at the construction site needs an effective monitoring method with accurate measurements of density in real-time, the ability to adjust immediately the compaction quality before cooling and without damaging the layer for quality control, quality assurance and performance prediction of the pavement layers.

2. Background

In fact, there has always been a need for a quick, accurate and non-destructive instrument for measuring in-place density in the paving industry. In the late fifties and early sixties, several manufacturers began experimenting with the use of low level radiation as a source of energy for measuring the in-place density of soil, aggregates and asphalt concrete. Over the ensuing years the paving industry has realized the importance of timely compaction results. The first generation of nuclear gauges were quite heavy and required a scaler attached by a long umbilical cord to the density device. The nuclear source shielding for operator protection was not yet refined and required the operator to read the results from a scaler at some distance from the gauge. Over the years nuclear gauge manufacturers have refined instrument accuracy and operator safety, however, owning and operating nuclear gauges still requires a State Radioactive Materials license. While nuclear density gauges have served paving industry well, the need for an instrument without the difficulties of a radioactive materials license, special handling and a more operator-friendly device was needed [7].

Within the last decade, non-nuclear technology has been developed for the purpose of measuring the density of in-place HMA (hot-mix asphalt) materials. These devices operate based on the principles of a constant voltage, radio frequency and electrical impedance for a current passing through the HMA material, adjusted for moisture variations and mix types [8]. PQI non-nuclear gauge offers: the ability to start the reading of the measurements straight ahead after the equipment is switched on, to take numerous density readings in a very short period of time, possibility to re-test results, low standard deviation between tests and less surface texture effect in comparison to nuclear gauge for example [7]. The PQI gauge is easy to use in practice, it can be stored and transported anywhere and can be purchased without a Radioactive Materials license. Unlike the nuclear gauges, it does not require extensive and periodic calibrations either by the manufacturer.

However, in order to standardize this technology, its accuracy must be equal or even better compared to the nuclear gauge and core measurement methods [9]. However, the readings provided by the PQI gauge are not absolute. They are relative measurements based on a given known value. Thus, it is necessary to 'calibrate' the device (or adjust the reference point) with a pavement section of known density and made from of the exact same material as the one where density measurements are desired [10]. A number of studies have been performed to determine the ability of the non-nuclear devices to accurately and precisely measure in-place density of asphalt pavements starting from the eighties. Two early studies [11-12] used both nuclear gauge and core methods to determine density. Analyses indicated no statistically significant differences in densities among the measurements, but the study did identify that the measured means were statistically different and that density variability was dependent on the type of mix. In the study of Rogge & Jackson [13] a large amount of data was collected, where it was reported that neither nuclear nor non-nuclear densities correlated well with core densities, and neither method was determined to be adequate for controlling field compaction. In all recent studies the outcome of the research is indicated by the significant factors affecting the pavement density after cold rolling compaction like: gauge type, proper gauge calibration, the influence of weather conditions on measurements, human factor such as correct placement of the gauge, the contact zone between HMA and gauge (evenness of the surface), humidity of the surface, pollution of the road (dust, leaves, organics), temperature of the road, mix type, thickness of the surface layers, etc.

In quality control it is not sufficient to only check the apparent density, but also the compaction temperature and the representative (mechanical) properties should be taken into account [6]. In the asphalt paving industry, both researchers and practitioners, postulate that the temperature of the asphalt mix during compaction is important for the final quality of the pavement. There are many parameters that influence the temperature of the asphalt mix. These include the ambient temperature, the temperature of the underlying surface, the compaction process and roller regimes, layer thickness, wind speed and rain. This makes it difficult for operators to predict the material temperature and adjust their actions to this information and to compact in the 'ideal compaction window'. The compaction window is based on viscosity-properties and the density that can be reached at this viscosity. To determine the compaction window based on mechanical properties, laboratory experiments and a field study are usually conducted. Compaction outside the compaction window can reduce the cracking toughness by 35% and increase the crack propagation rate by 40%, despite the target density being reached [6]. It is advisable to determine the compaction window based on temperature and the resulting mechanical properties instead of bitumen viscosity and the density that can be reached at this viscosity.

Also, a new trend is noticed in road construction engineering: the implementation of internet of things. In the ROAD_IT project (University of Antwerp & Belgian Road Research Centre) an IT-architecture is demonstrated to evaluate the digital data transfer of different types of new technologies during asphalt production and the laying process. Density measurements during compaction, between e.g. an infrared line scanner on the finisher and the roller compactors, can improve the compaction homogeneity by adjusting the compaction pattern of the rollers. Moreover, when the gauge is equipped with a GPS system, the compaction degree can be set for each measured point and stored for later use. This work method will decrease a posteriori tests, which may damage the pavement.

3. Data collection

In this paper the method using a non-nuclear density gauge is evaluated for in-place density measurements, based on a work at Brussels Airport during the rehabilitation project of runway 01/19 and at the area of the Port of Antwerp. The density tests were performed using drilled cores, a non-nuclear gauge TransTech PQI-380 and a nuclear density device Troxler 3450.

A comprehensive test program was set up to evaluate how the TransTech PQI380 equipment works in terms of accuracy and precision. As it is known, a critical step in using impedance gauges effectively is to calibrate them in a manner that will increase the accuracy of results. Density measurements are relative measures of compaction, and can thus be adjusted mathematically in order to more accurately represent the “true” density of the pavement. Although an “absolutely true” measure of pavement density cannot be reasonably achieved, the most accurate measures are typically believed to result from the bulk specific gravity measurement of a pavement core drilled from the compacted mat. Therefore, an alternative measure of density is believed to be accurate if it can produce results similar to those generated by core densities [14]. The use of the non-nuclear density gauge is an alternative method avoiding a high number of core drillings for controlling the compaction process performing a continuous measurement of the compaction quality where cores are prohibited (at the edges of the pavement, airport runaway pavement, bridges, parking lots on the roof, etc.). In U.S. this device complies with ASTM (D7113-05) and AASHTO (T 343-12) standards.

Data for this study were collected from a certain selection of points (in total of 168 points) along and across seven newly paved test tracks; two grading HMA mix types (Marshall-designed asphalt; MA 0/10 and MA 0/14) are used with different compaction ratios asked to the roller operator (normally, less and extra compacted) at Antwerp Euro Terminal (see Figure 1). Each test track was constructed by two parallel finishers (width of each finisher - 3.75m). This way, a comparison can be made between different finishers, compaction grade, the side effect and differences in mix types. Drilled cores were collected and tested. Also others tests like grooving were performed [15], but they are out of the scope of this contribution. In this study, only a comparison is made between drilled cores and PQI-measurements, compared to the optimal compaction, derived from the technical justification note (TJN).

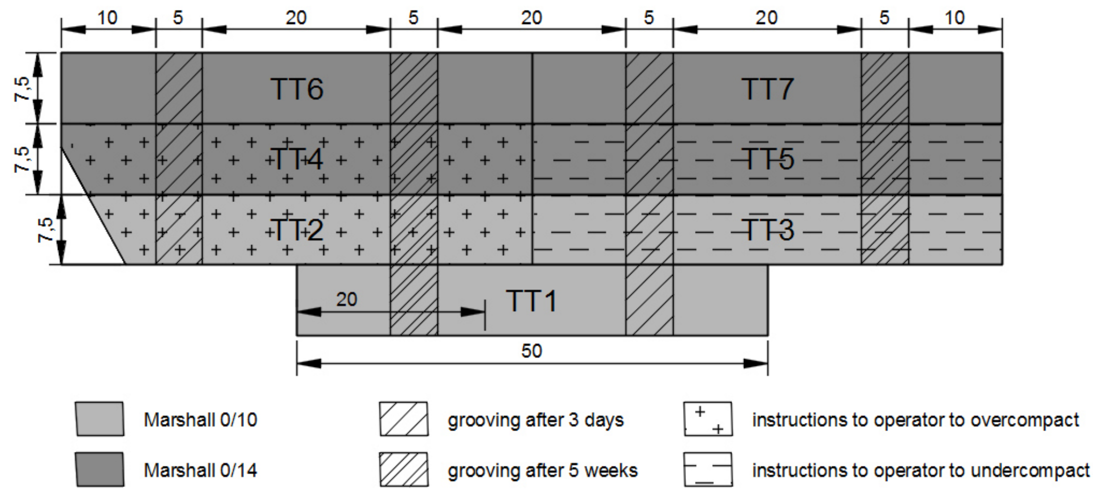

Figure 1. Overview of the full-scale test tracks (TT).

To estimate the density at each test track at different locations six measuring points were performed immediately after total rolling process. During the first test, the gauge was outlined with chalk and numbered for an easy detection. Between tests, the gauge was lifted from the pavement and then placed again at the same location. All the measurements were carried out with offset value 0. The offset value was subsequently determined on the basis of drilled cores. The nuclear density measurements were performed by Belgian Road Research Center at locations determined by University of Antwerp and carried out with the Troxler 3450 gamma density meter. A total of 35 measurements were carried out, five measurements per test section. The results of the non-nuclear density meter and the density determined by cores were compared. Temperature measurements during the day were: in the morning ±5°C and in the afternoon ±12°C. There was no wind and it was dry and sunny. The surface temperature of HMA was taken during the first test using a ScanTemp440 infrared thermometer. Surface temperature during the measurements were indicated in the readings of PQI-measurements.

4. Data analysis

Surface temperature measurements showed that the temperature of HMA surface varied between 179 and 147 °C with an average of 163 °C. In order to observe the effect of how temperature influences the density of asphalt, the non-nuclear gauge was repositioned twice in the test tracks 1&3 with time difference of 3-4 hours. In theory, as materials cool, they tend to shrink or become denser [16]. This process can be observed from the field data in figure 2 when the asphalt temperature decreased from 38°C to 31 °C and the measured density increased (in particular it can be seen in figure 2(right)).

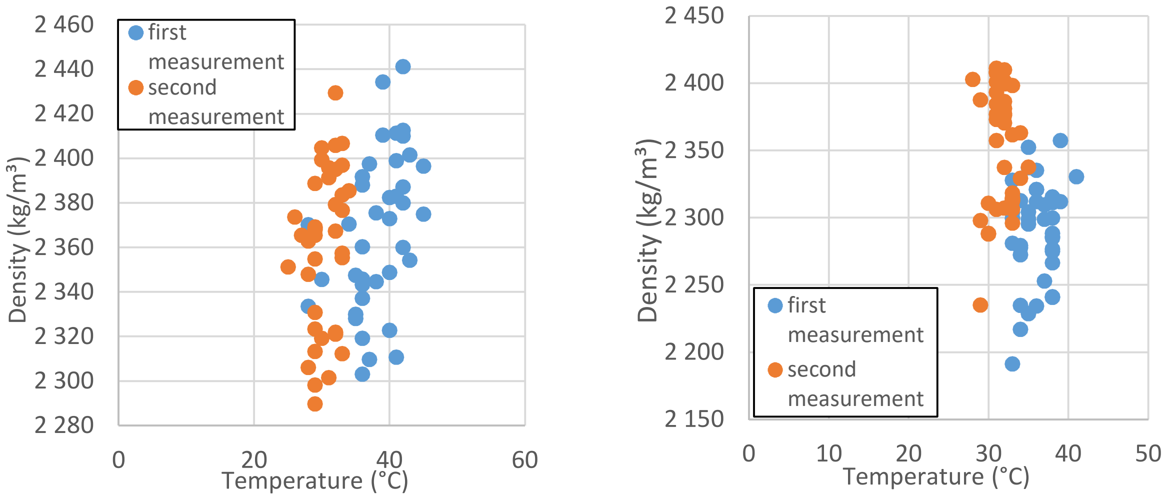

Figure 2. Densities compared to PQI – test track 1 (left) &3 (right).

The measurements were performed on the test tracks (see figure 1) at several positions, approximately each 10 m along the test track; 6 measurements per width are taken, taken into account that each test track was constructed by two parallel finishers. In that way it was possible to evaluate how the compaction evolves from left to right side (including middle part) of each lane and along the test track, and if a difference in compaction between two finishers at equal conditions is apparent. In this paper only the comparison with nuclear measurements and core results are reported. The average compaction from those measurements is summarized in table 1. During the measurements it has been noticed that there might be a slight difference in the results if the gauge is not firmly connected to the surface in each measurement (one of the reasons could be because of the unevenness of the surface). Also it was observed that the middle part of the lane was always better compacted than the sides. The compaction degree (%TJN) - is expressed as: PQI-measurement of the density after last rolling or density from cores, divided by the optimal density derived from the technical justification note (TJN) approved by the Flemish Road Agency. For example, if the PQI-measurement equals the optimal density a value of 100% is obtained. The difference between normally compacted test track, less compacted and extra compacted is the number of rolling movements on the location, without knowing if this difference does affect the compaction degree.

The primary objective of this study was to establish a correlation, using the non-nuclear method, nuclear method and drilling cores, between asphalt density measured immediately after finishing cold rolling. As it can be seen from the figures 3&4, the results obtained from PQI-measurements differ for 1-3% from drilled cores results, similar as for the nuclear measurements. In these figures also the deviation with the theoretical value from the technical justification note is observed. Points at the end of test tracks such as B5 and B10 show high deviations from measuring points in the middle of test tracks. This can be seen as a clear signal of less compaction at the start and end of the tracks. Both figures demonstrate also a trend for the different compaction conditions - however outliners are registered (e.g. B23). The results of PQI, the nuclear measurements and the cores are consistent. As observed in table 1, there is no large difference in compaction in spite that the roller operation had clear instructions to over- or undercompact. This demonstrates again that a tool like the PQI is necessary to control the compaction. In a subsequent project for Brussels Airport, the PQI is used just after first compaction movement until the correct compaction is obtained. Considering this, the PQI-380 non-nuclear gauge could be advised as a unique tool for continuous or a posteriori asphalt pavement density measurements and in time to be a part of the standard quality control process in the Flemish region.

Table 1. PQI-measurements compaction of test tracks pavements (B - are measuring points)

HMA mix type	Test track	Compaction degree PQI (%TJN):	Compaction degree Core (%TJN):	Test track target condition
	1	99	98	normally compacted (B1-B5)
MA 0/10	2	100	100	extra compacted (B6-B10)
	3	97	97	less compacted (B11-B15)
	4	101	100	extra compacted (B16-B20)
MA 0/14	5	98	98	less compacted (B21-B25)
	6	100	99	normally compacted (B26-B30)
	7	98	98	normally compacted (B31-B35)

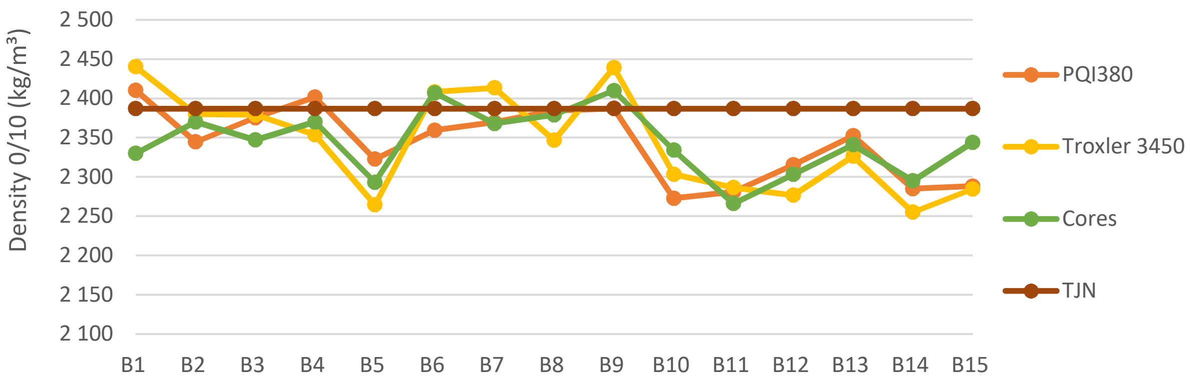

Figure 3. Density result comparison for HMA 0/10.

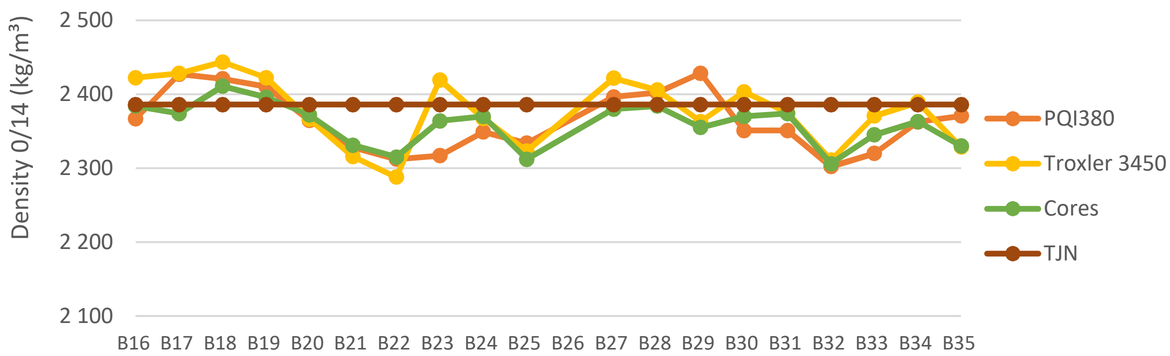

Figure 4. Density result comparison for HMA 0/14.

It is commonly known that compaction is always better in the middle of the lane (width 3.5m), in order to see the compaction homogeneity of asphalt lanes PQI-measurements were taken during another project in the Port of Antwerp (PSA Terminal). The results are reflected in the table 2. It can be seen that the middle part of the lane is better compacted than the sides of the lane, also there is no clear distinction between the right zone that is applied against another lane and the left zone which is free.

Table 2. PQI-measurements compaction of test track, expressed as [PQI density/TJN*100%] (L - left, ML – middle left, M - middle, MR – middle right, R - right).

	L	ML	M	MR	R
Location 1					
SVM (%)	97.8	99.8	100.3	99.9	100.3
SVM (kg/m^3)	2352	2399	2410	2401	2411
T (°C)	62	70	71	72	76
Location 2					
SVM (%)	96.7	98.1	99.6	99.2	98.5
SVM (kg/m^3)	2352	2355	2393	2385	2368
T (°C)	73	72	71	70	73
Location 3					
SVM (%)	99.5	100.7	98.8	98.6	98.0
SVM (kg/m^3)	2392	2421	2376	2369	2355
T (°C)	74	73	71	71	73

5. Conclusions

In the present study results from different projects, where a non-nuclear gauge TransTech PQI-380 was used by University of Antwerp, are summarized. The purpose of the present investigation was to clarify whether a PQI non-nuclear density gauge can provide precise measurements in comparison with for example cores or a nuclear gauge. This device is an easy-to-use tool for site supervisors during the compaction process to determine whether the pavement is compacted properly or not and which locations require more compaction. After more validation, this device could be complying with the local standards and selected as one of the instruments for permanent quality control e.g. in a tender, as an effective tool for density measurements of pavements, and in cases where cores are prohibited.

The important results of this study can be concluded as follows:

1. During the rolling process immediate evaluation of the compaction process is important to increase the efficiency by permanent control during the time that the roller passes; local adjustments can be accomplished by PQI-measurements during the compaction process and not after reporting the cores results for example;
2. It can be a low cost time efficient measurement after a one time investment;
3. Also a lower number of cores is required which induces less damaged newly constructed roads or not damaged at all in the case of strict regulations like at the airports;
4. After the rolling process it is possible to determine the homogeneity of a lane over the relative measurements of the density at a constant temperature and to determine the absolute values of the density at various locations by correlating them with (single) core samples at known locations;
5. The process control provides a tool to obtain a higher quality level and durability effect by an increased service life and avoids repaving; resulting in decreased costs and carbon-footprint;
6. This device can be used as an intermediate control between new technologies such as an infrared-line scanner behind the finisher and so-called ‘intelligent compactors’;
7. Differences between start and end compaction process can be observed in the test tracks. It would be useful to register these bad points for later evaluation e.g. cracks, rutting and ravelling;
8. As disadvantages could be mentioned: training for an effective usage of the PQI non-nuclear gauge is required, the offset absolute value must be adapted to the local situation, optimal

compaction or current mix data are required since actual measurement of the density of an unknown mix in place without initial values is not possible; measured density values are temperature dependent. However, all of these disadvantages can be anticipated by a manual, training and knowing the limits of the method.

Acknowledgements
The authors would like to thank the personnel of the Infrastructure & Real Estate department of Brussels Airport Company and the contractor NV Aswebo. The authors would also like to acknowledge the support of the Belgian Road Research Centre who performed the measurements with the gamma density measurement device. Without their support this research would not have been possible.

References
[1] Peng B, Cai C, Yin G, Li W and Zhan Y 2015 Evaluation system for CO_2 emission of hot asphalt mixture *Journal of traffic and transportation engineering* **2**(2) pp 116-124
[2] International Energy Agency 2016 *Key world energy statistics*
[3] Huerne H L 2004 *Compaction of Asphalt Road Pavements Using Finite Elements and Critical State Theory* (PhD thesis University of Twente Enschede, The Netherlands) p 319
[4] Decker D S 2006 State-of-the-Practice for Cold-Weather Compaction of Hot-Mix Asphalt Pavements *Factors Affecting Compaction of Asphalt Pavements* (Transportation Research E-Circular Issue No. E-C105 (TRB Washingron DC USA) pp 27-33
[5] Miller S R, Hartmann T and Dorée AG 2011 Measuring and visualizing Hot Mix Asphalt Concrete Paving Operations *Automation in construction* **20** pp 474-81
[6] Bijleveld F, Miller S, De Bondt A and Doree A 2012 Too hot to handle, too cold to control – influence of compaction temperature on the mechanical properties of asphalt *Proc. 5th Eurasphalt & Eurobitume Congress (Istanbul, Turkey)* pp A5EE-231
[7] Sully-Miller Contraction CO 2000 *A summary of operational differences between nuclear and non-nuclear density measuring instruments* p 5
[8] Von Quintus H L, Minchin Jr R E, Nazarian S, Maser K R and Prowell B 2009 NDT Technology for quality assurance of HMA pavement construction *National Cooperative Highway Research Program Report 626* (TRB Washingron DC USA) p 112
[9] Zhuang Z 2011 *Effectiveness study of Non-Nuclear Gauge for Hot Mix Asphalt (HMA) Pavement Construction* (University of Nebraska-Lincoln, USA)
[10] Romero P 2002 *Evaluation of non-nuclear gauges to measure density of hot-mix asphalt pavements Final Report* (Department of Civil and Environmental Engineering, University of Utah USA)
[11] Sanders S R, Rath D and Parker F 1994 Comparison and core pavement density measurement *Journal of Transportation Engineering* **120**(6) pp 953-66
[12] Hanna A S, Russell J S, Noyce D A and Schmitt R L 1995 *Asphaltic pavement density measurement comparison using coring and nuclear methods - International Technical Peport* (University of Winsconsin-Madison USA)
[13] Rogge D F and Jackson M A 1999 Compaction and Measurement of Field Density for Oregon Open-Graded (F-Mix) Asphalt Pavement *Final Report SPR 386* (US: Department of Civil, Construction, and Environmental Engineering, Oregon State University)
[14] Williams S G 2008 Non-nuclear methods for HMA density measurements *MBTC 2075 Final Report* (University of Arkansas USA) p 77
[15] Vuye C, Couscheir K, Lauriks L, Van den bergh W and Van Bouwel Ph 2017 The influence of mixture composition, adhesion promotor and compaction degree on the groove stability of grooved Marshall asphalt *Proc. BESTInfra 2017 (Prague)*
[16] Hanna A S, Lee M-J, Schoenfelder S M and Lee C 2008 Temperature-density relationship of hot-mix asphalt pavement after completed rolling *Canadian Journal of Civil Engineering* **35** pp 1468-75