Improvement of longitudinal asphalt joints performance by using induction heating

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Actual construction practices of asphalt joints focus mainly on avoiding the penetration of water into the pavement structure. Only little attempt has been made to enhance load transfer mechanisms. As a result, density of the asphalt concrete near joints is usually lower than in the rest of the pavement. This experimental work aimed at improving the overall performance of joints in asphalt pavements. The approach is based on the induction heating of asphalt pavements, locally in the region of the joints. To that end, different designs of longitudinal asphalt joints were built and tested, including commercial treatments (self-adhesive tape or bituminous sealing) and innovative asphalt mixtures with iron particles as additives. Results showed that the proposed designs would improve the performance of joints compared to commercial treatments.

Keywords: asphalt joints; induction heating; iron particles; mechanical performance

Introduction

The connections between two asphalt road lanes are called joints and they are usually the weakest locations in a pavement. The effect of traffic loading and environmental conditions like moisture or temperature influences negatively the performance of joints, causing premature failure of the road. Deteriorated joints may trigger fast loss of functionality of pavements causing serious safety problems, reduction of driving comfort and increase of traffic noise.

There are different commercial methods for improving joints in asphalt pavements such as the use of joint tapes and bituminous coatings. However, these solutions focus only on adding waterproofness to the structure and not on load transfer capabilities. Other innovative techniques for improving functionality of the joints include pre-heating with torch or infrared heating devices. In spite of the fact that longitudinal joints are important structural elements in pavements, surprisingly little research has been carried out for increasing their performance. Most international publications about joints are technical notes with recommendations about how to lay and compact a joint (AAPA, 1997, Buncher, 2012). Main conclusion of these reports is that cracking of longitudinal joint is primarily caused by substantial differences in densities on either side of the joint. This is also related with the regime of the roller compaction and the geometry of the joining surfaces (Ghafoori Roozbahany, Partl & Witkiewicz, 2013). Another important topic discussed in literature is the possibility of transverse drainage of water through longitudinal joint in porous asphalt (Wang & Oeser, 2015). In that work, different types of joints constructions are considered, including pre-heating of the contact area with an infrared source. Taking into consideration the shortcomings of actual joint construction techniques and the difficulties to combine correct compaction regime with optimal preheating of contact surface of the joints, the use of induction heating technology could be a promising solution. This innovative treatment would improve durability and functionality of joints thanks to the sealing of the discontinuities of the asphalt material after construction of the joint. Moreover, this solution would offer a maintenance option by artificially heating asphalt pavements for healing purposes. It has been experimentally shown that microcracks generated by repeated traffic loads and thermal stresses at low temperature can be closed before they grow and propagate in the road structure (Garcia, Bueno, Norambuena-Contreras, & Partl, 2013). In this way, it is possible to improve the cohesive and adhesive bonds in asphalt before failure occurs, thus extending pavement’s life-span.

The goal of this work is to evaluate the use of induction heating for the improvement of asphalt joints performance. Specifically, the experimental setup was designed to investigate materials and construction techniques for longitudinal joints. This approach was focused on the incorporation of electrical conductive additives into the asphalt material in order to allow an extra-compaction on both sides of the joint, after locally reaching the required temperature through induction heating. Performance of the new joint designs is evaluated and compared to that obtained with traditional joint construction techniques. The analysis of economic aspects of this technique, as well as questions about the effect of iron on the durability of the pavement and their sustainability are beyond the scope of the present study.

Materials and Methods

Materials and compaction process

A number of different joint designs were built at lab scale by reproducing a process with similar compression and tension strain fields as obtained in a pavement construction. In order to obtain representative joints in 1.8 m long asphalt slabs, a steel roller vibratory compactor was used (Bueno, Arraigada, & Partl, 2016). An asphalt concrete mixture (AC 11) with bitumen 50/70 (5.4% wt.) and 4.5% air void content, was compacted until reaching a thickness of 4 cm by controlling different experimental parameters such as the number of rolling passes. The compaction temperature was also monitored using a full colour infrared camera.

In order to simulate a longitudinal joint, a defined amount of asphalt mixture was compacted as first lane of the system. Once this first lane cooled down, the same amount of mixture was laid and compacted for preparing the second lane of the structure. The different designs involved compacted slabs with cold-hot joints (Table 1). In order to assess the effect of the difference of temperature during the compaction process, the first lane of the plate was allowed to cool down to 22°C before the asphalt mixture for the second lane was laid and compacted at high temperature (ca. 130 °C)

(Figure 1). For joint design A, taken as control, two different alternatives were prepared, with one lose free edge at the later joint location during the compaction of the first lane (design A1) and with vertical lateral confinement for the joint using a wooden board (design A2).

Table 1. Designs of asphalt joints.

Design	Type of Joint
Design A1	Free edge
Design A2	90° Lateral confinement
Design B	90° Sawed and self-adhesive tape
Design C	90° Sawed and bituminous coating
Design D1	Free edge and iron particles
Design D2	90° Lateral confinement and iron particles

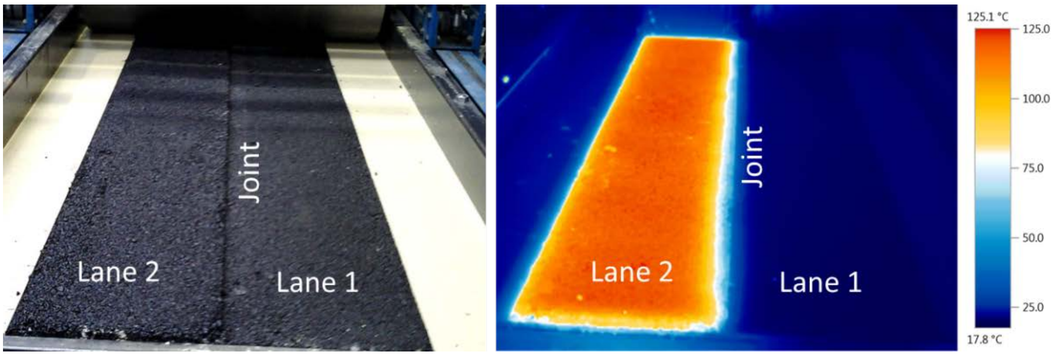

Figure 1. Detail of compaction process for hot-cold joints. Real image (left) and IR-image (right) with the temperature distribution for a hot-cold joint during the compaction of the second lane.

Following a similar procedure, other asphalt slabs were compacted with different designs of joints. They ranged from conventional commercial treatments (self-adhesive tape or bituminous sealing) to innovative designs including mixtures with iron particles as additives. First, cold-hot joints with different commercial treatments were constructed. After compaction of the first lane, the edge of the joint was sawed. A self-adhesive commercial tape (TOK-Band SK® 1 cm thickness) was applied directly to the cold seam before second compaction for design B. In case of design C, a commercial bituminous coating (TOK-Plast ®) was applied to the cold interface as sealing.

Besides, experimental designs were prepared by using iron particles with size range between 0.6-1.0 mm as conductive additives incorporated into the asphalt mixture (14% wt. of mixture) in order to use induction heating. This material with additives was used in both lanes only in the area around the joint. After construction, an induction heating treatment and an extra-compaction process with a portable roller (ca. 105 kg) after heating the joint area up to 130 °C (Figure 2) were carried out as additional steps for the designs D. Previously, hot-cold joints without (design D1) and with (design D2) lateral confinement during the compaction of the first lane were built. It is important to remark that the method without lateral confinement for designs D1 and A1 was expected to have some practical advantages because it would allow better mingling and interlocking of the aggregate skeleton. Moreover, this would also avoid the conventional sawing process, saving a significant amount of material.

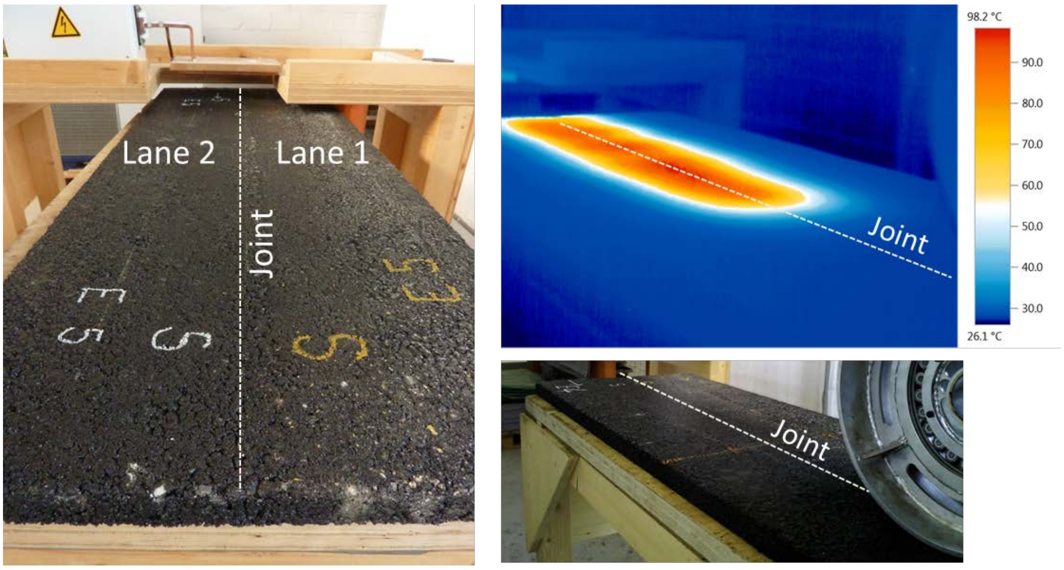

Figure 2. Details of induction heating treatment and extra-compaction process of the joint type D.

Induction heating set up

The working principle of the induction heating process is based on the application to the pavement of an electromagnetic field generated with an inductor coil. If an asphalt mixture is modified with electrically conductive particles, the electromagnetic radiation will increase their temperature due to the Joule effect (Jeoffroy, Koulialias, Yoon, Partl & Studart, 2016). As a consequence, the heat will reduce the viscosity of the asphalt material to allow an extra-compaction process. In this work, the induction heating experiments were performed with a 30 kW generator at a maximum frequency of 80 kHz. The setup and dimensions of the induction coil can be found elsewhere (Bueno et al., 2016). The heating area around the joint was kept closely to 130°C during the extra-compaction process with the portable cylinder. The compaction temperature was controlled using the infrared camera to avoid overheating effects that could damage the binder.

Mechanical characterization method

In order to evaluate the stiffness and the fracture behaviour of the joints, prismatic specimens (40 mm x 40 mm x 500 mm) were cut from the different slabs perpendicular to the joints. Four point bending (4PB) tests for each design were conducted at 10°C to characterize the stiffness of bituminous mixtures in the linear viscoelastic range. Following the procedure described in the European standard (CEN, 2012), the so called stiffness modulus was calculated applying sinusoidal strains under 50 μstr at 10 Hz. The deformation of the specimen as well as the phase lag between the force signal and the displacement signal were then measured as a function of time. Ten specimens from each design were conditioned in the climate chamber at the test temperature overnight before the test.

Further, fracture tests under displacement mode (1 mm/min) at 0°C were performed for the different designs of asphalt joints using the 4PB configuration as well.

Results and discussions

Figure 3 shows the effect of the different designs on the stiffness of the joints. It was found that the conventional joint treatments, designs B and C with adhesive tape and bituminous coating respectively, presented lower values than the specimens of designs A did. Nevertheless, design A2 showed higher values in comparison to those obtained for commercial treatments but slightly lower than those from design A1. In this case, the use of lateral confinement during the compaction of the first lane (vertical joint 0° angle) could cause a lack of mechanical interlock between the two parts of the structure. This discontinuity of the granular skeleton through the slab made sometimes the joint not resistant even to small vibrations from the cutting machine. In this sense, it is significant to remark the dispersity of results obtained for specimens with design A2.

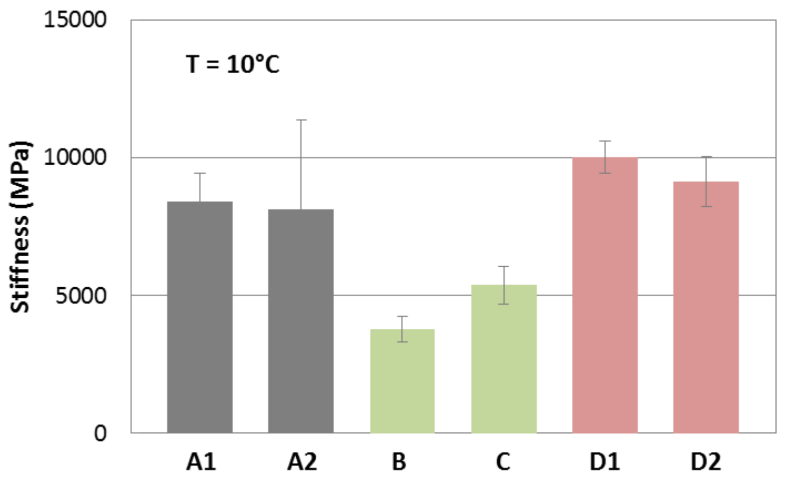

Figure 3. Stiffness at 10 °C of the different joint designs.

Further, two different alternatives were carried out considering design D, namely D1 and D2. After construction of a cold-hot joint with (D2) and without (D1) lateral confinement during the compaction of the first asphalt lane, the effect of an induction heating procedure until 130°C plus an extra-compacting process was evaluated. This final compaction after the induction heating procedure led to a better performance in both cases. This treatment increased the stiffness of the experimental joint as compared to those obtained for designs A1 and A2. This fact demonstrated the importance of the temperature during the compaction of the asphalt mixture in the joint. As happened for designs A1, the compaction without lateral confinement (design D1) improved the interlocking between the two lanes leading to better results than those found after the process with confinement and vertical joint (design D2).

Moreover, the resistance to fracture of the different designs can be analysed with the maximum force reached during the test under displacement control (Figure 4). Again, it seems clear that the innovative designs D with iron particles as conductive additives provided better load transfer. These specimens reached values up to four times higher than the rest of joints. The extra-compaction around the joint at high temperature could improve the adhesion between both interfaces. Nevertheless, the fracture resistance found for design D1 showed that the low density obtained in the first lane during the compaction process (no lateral confinement) is significant for the whole performance of this kind of design. However, it obtained a better result than conventional solutions.

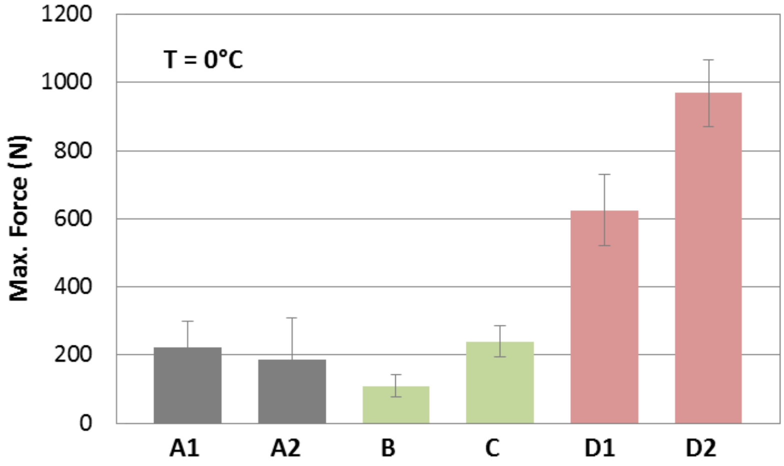

Figure 4. Maximum force reached until fracture at 0 °C of the different joint designs.

Figure 5 compiles a set of images with details of the fracture obtained for each type of joint. It shows that the crack in design A is following the weakest path, sometimes even going through the fracture of mineral aggregates. Designs B and C presented vertical fractures placed on the interfaces due to the loss of adhesion in the joints. It can be seen that the crack is defined by the bond between the adhesive tape and the edge of the sawed face of the first asphalt lane. The influence of the compaction process after induction heating is also shown in Figure 5. In this case, specimens from the slabs subject to the experimental procedure (designs D) did not fracture through the joint. This fact confirms that the treated joint was not the weakest point in the specimen and that the material behaved as a uniform asphalt mixture without joints. Hence, ideal load transfer was reached in that case.

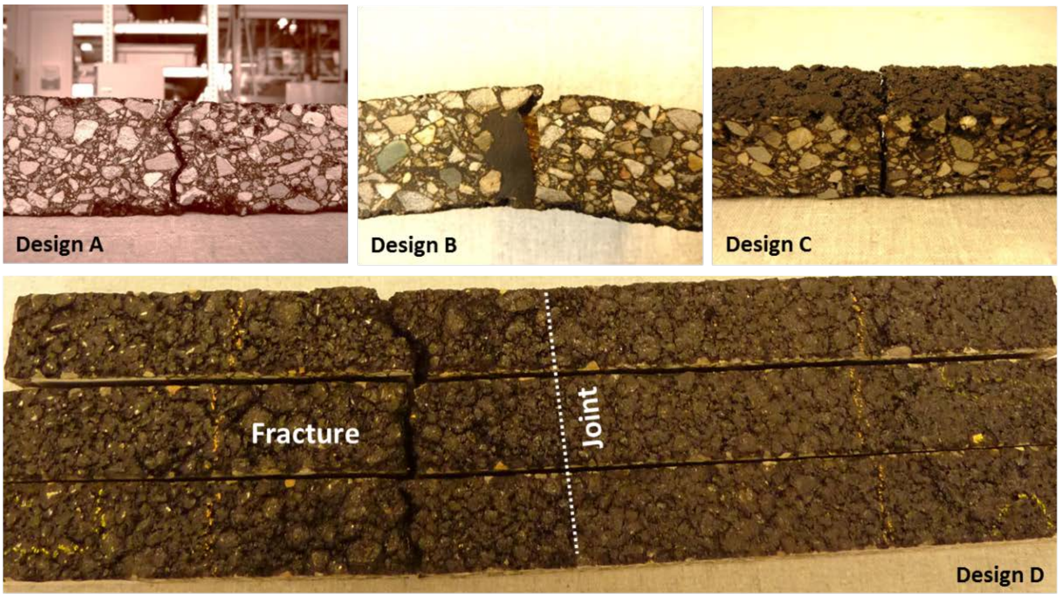

Figure 5. Details of fracture paths for different designs joints.

Conclusions

This work focused on the evaluation of the induction heating technology to improve longitudinal joints in asphalt concrete pavements. To this end, electrical conductive additives were added to the asphalt mixture to locally increase the temperature of the material and carry out an extra-compaction procedure at both sides of the joint. First, an initial compaction procedure was developed using a roller compactor to reproduce a pavement construction and monitoring a number of parameters such temperature and number of passes. Following this procedure, asphalt slabs were compacted with different designs of joints, ranging from hot-cold joints and conventional treatments (self-adhesive tape or bituminous sealing) to innovative designs with iron particles as additives. Moreover, the effect of lateral confinement during the compaction of the first lane was studied. Results showed that an extra-compaction after a local heating improved the performance as compared to commercial treatments. This experimental method increased the density in the joint and, in this way, the interlocking throughout this discontinuity. In addition, the compaction without lateral confinement led to a kind of angular joint which also enhances interlocking of the aggregate skeleton. Nevertheless, this configuration produced worse values of fracture resistance at low temperature.

In order to optimize this technique, operating parameters such as type of the mixture (bitumen) as well as type and amount of conductive additives will be studied in the upcoming research works.

Acknowledgments

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