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Monitoring the flow of asphalt mixtures compacted on two different rough surfaces

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ABSTRACT: Asphalt compaction is one of the most important processes in road construction as it forms the final structure of an asphalt pavement layer. In spite of its importance, flow mechanisms regarding arrangements and displacement of aggregates in the asphalt mixture during that process is still poorly understood. This lack of knowledge is often blamed for the observed differences between field and laboratory test results. In order to overcome this problem, effective and more realistic devices are needed for simulating the flow behavior of asphalt mixtures at laboratory scale along with innovative tracking methods for investigating both laboratory and field compaction. In this study, a recently developed laboratory scale compaction flow simulator CFT (compaction flow test) was used along with a monitoring technique to investigate the behavior of two structurally different asphalt mixtures compacted on surfaces with two different roughness geometries. The results demonstrated the efficiency of the suggested technique for studying flow behavior of asphalt mixtures compacted on different surfaces.

1 INTRODUCTION

Constructing an asphalt wearing course normally consists of three major steps: mixture production in an asphalt plant, placing the asphalt with a paver followed by compaction with a roller compactor. The compaction causes the rearrangement of the aggregates of the freshly laid asphalt mixture composing the final aggregate skeleton for the pavement layer. Hence, an adequate compaction is the key for avoiding any premature failures in the top layer. Conducting the most effective compaction requires sound knowledge on how different asphalt mixtures behave under compaction loads, thus allowing continuous adjustments and quality improvement during road construction. In the following, firstly, existing methods for understanding the mixture behavior during the compaction phase are presented together with a discussion on the shortcomings; secondly, recent efforts by the authors are presented aiming at introducing a methodology for providing better insight into the structural changes during the compaction phase; finally, some of the results obtained from the proposed method are presented.

2 BACKGROUND

Due to its high impact on the final quality of the pavements, compaction has always been a hot topic in asphalt industry and therefore been subject for numerous of studies. As a result, there are different types of laboratory compaction simulators; in the following, two compaction simulators that are mostly used in asphalt industry are briefly presented.

2.1 *Laboratory compaction simulators*

Existing standard compaction simulators such as Marshall hammer, White (1985), and gyratory compactor, Hines et al. (1995), are frequently used in research and also in asphalt industry. These simulators are used in the mix design procedures and provide information about the compaction effort required for reaching the desired density for different asphalt mixtures. Most of these devices have confined loading configuration, meaning that the asphalt mixture in the compaction mold is compacted over a stiff plate that covers its whole surface, Figure 1a; this type of loading mostly provides vertical rearrangement of the particles in the mixture and largely ignores the lateral flow of particles away from the field compaction loading as shown in Figure 1b. Since lateral flow behavior has been recognized as an influential parameter on the quality of the pavements, Kandhal et al. (1997) and Mollenhauer et al. (2016), it appears that neglecting lateral flow effects in the laboratory methodology is one of the reasons for the existing observed differences between field and laboratory test results. In addition, it has been proven in different studies, e.g. Partl et al. (2007), that the aforementioned compaction simulators with similar loading configurations cause non-uniform rearrangements when comparing the movements of the aggregates near the walls and in the center of the mold; such a difference seems to be another shortcoming of these laboratory scale methods that prevents them from representing the field compaction.

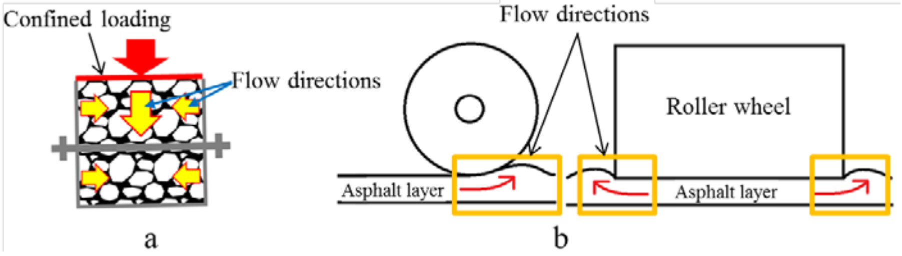

Figure 1. The expected lateral flow directions (a) in the laboratory (gyratory compactor); (b) in the field

Hence, in order to avoid the confined loading configuration of the existing laboratory tests and for simulating the flow of asphalt mixtures during compaction in the field, the authors developed a simplified compaction flow test (CFT), that was presented in an earlier study, Ghafoori Roozbahany et al. (2015a), and is briefly described below.

2.2 *Compaction flow test (CFT)*

The CFT was developed focusing on the flow phenomena during the initial stage of asphalt compaction (breakdown), where most of the flow occurs. The CFT setup consists of a square mold of 150x100x100mm^3 that is filled with an asphalt mixture, representing an asphalt layer in its loose condition after being laid on the road by the paver; the CFT specimen is then loaded from one side of the mold with a stiff prismatic loading strip that acts as simplified steel roller for applying an unilateral static compression load with a servo-hydraulic 100kN testing machine (Figure 2a). The advantage of this method is that almost two third of the specimen is left unloaded, thus allowing the aggregates in the mixture to rearrange not only vertically but also to move laterally. Although the test setting allows both force and displacement control modes, the CFT has been used mostly in the displacement control mode which better suited for studying the load-displacement behavior as well as the uplift formed on the load-free surface of the specimen

(Figure 2b). Changes in uplift are mostly visible with naked eyes and for more accurate measurements, in an earlier study, Ghafoori Roozbahany et al. (2015b), a distant measuring ultrasound sensor was used; the results of the study demonstrated that the CFT enables to differentiate between mixtures with different characteristics, such as gradations, binder content, binder type since the uplift and the load vs displacement curves give a more complete picture about the compactability of the mixtures.

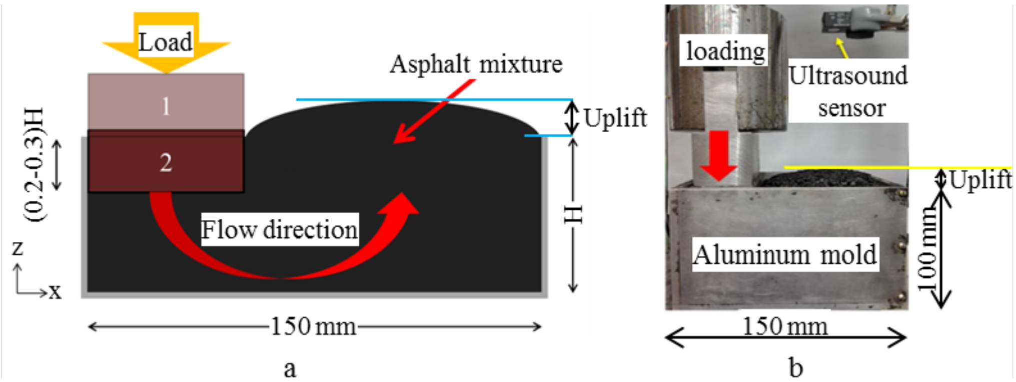

Figure 2. Compaction flow test setting a) Schema with starting position 1 and end position 2, b) Setup

For practical application measuring force, displacement and uplift in the CFT may be sufficient. However, additional monitoring systems such as X-ray computed tomography (CT) enable an even closer look to the internal movements of the components in the mixtures during CFT, Ghafoori Roozbahany et al. (2015a). Promising results obtained from this monitoring method encourages further investigation of critical cases such as rearrangements of asphalt particles at the interface between the overlay and its bottom layer. Normally, in practice, deteriorated and distressed pavement material is milled away before placing an overlay on the bottom layer. Depending on the size of the teeth used in the milling, different irregularities on the road are created. Such bottom surface differences can change the flow behavior of the newly laid overlay during its compaction which is the main focus of this study.

Hence, in this study, first, a methodology that enables conducting active tracking of the flow during the CFT is presented; then, this methodology is applied for investigating the impact of CFT on two structurally different mixtures compacted on two idealized surfaces with different roughness geometries.

3 METHODOLOGY

3.1 X-ray investigation

X-ray computed tomography (CT) has now been used for quite some time for obtaining the internal changes of asphalt mixture specimens, Masad et al. 2002. The CT images are more widely used for the already compacted specimens and only few studies are focused on the evolution of the particles during the compaction. In the literature, Partl et al. (2007), and also as part of an earlier study carried out by the authors, Ghafoori Roozbahany et al. 2015a, the 3D imaging was used at different steps of the testing. This requires repeated heating, loading, cooling and CT-imaging. In spite of its usefulness, this laborious method has some disadvantages: firstly, repeated heating and cooling causes negative effects such as unwanted movements of particles and binder aging; secondly, due to the complicated image post processing, this method might be very time-consuming. Hence, a simpler, faster and more efficient method for tracking the flow behavior of different asphalt mixtures was required. Similar to a previous study, Ghafoori roozbahany et al. (2015b), the authors utilized a load frame inside an X-ray CT machine with the capacity of the 220kV (Figure 3). With a fixed X-ray source, this method was convenient for obtaining 2D radiography images of the movements within the specimens during the tests without requiring any repeated heating, cooling and removing the specimen from the load frame.

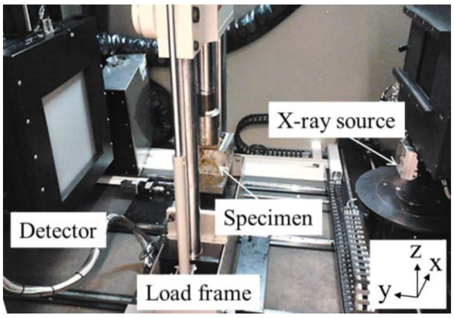

Figure 3. Using a servo-hydraulic load frame inside the X-ray machine

On the other hand, there are also some limitations with the 2D imaging; the density differences are translated to different grayscale levels that determine the brightness and darkness of the acquired 2D images. Similarity of the density of the components within an asphalt mixture makes it difficult to follow their flow using 2D images; besides, the 2D images might miss details about the movements in the perpendicular plane to the detector. Hence, for better contrast in the images, particles with higher density than asphalt mixtures but not larger than the maximum aggregate size (NMAS) were embedded in the asphalt mixtures. This method was developed by the authors in the earlier study, Ghafoori Roozbahany et al. 2015a, on a mixture consisting of glass balls, with similar density to aggregates, and a lubricant, with similar viscosity to bitumen at compaction temperature. The embedded particles in this mixture consisted of small steel pins that were glued inside rounded hollow glass beads as large as 10mm and then placed at different locations of the specimens. An example of the embedded pins is shown in Figure 4a.

This methodology for tracking the embedded pins in the hollow glass beads appeared effective in obtaining a rough picture of the movements at different locations of the specimens during the CFT. However, since real mixtures were used in this study, it was decided to use screws as embedded particles for obtaining better interaction with the angular aggregates, Figure 4b.

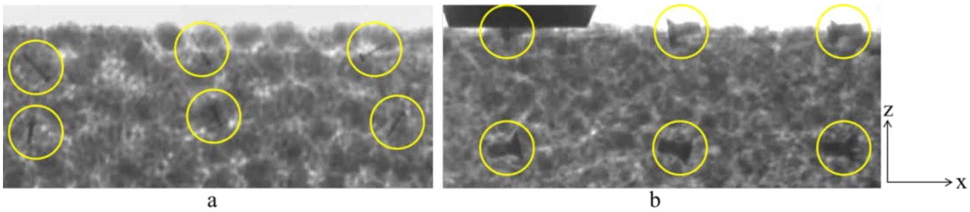

Figure 4. Examples of the embedment used for tracking, marked in circles; (a) pins embedded in hollow glass bead; (b) screws

During the trial tests, steel embedment showed only very little lateral movements in the x-y plane when placed far away from the side walls; hence, it was decided to place all the embedment in the center of the x-y plane and at different heights of the x-z plane as schematically shown in Figure 5.

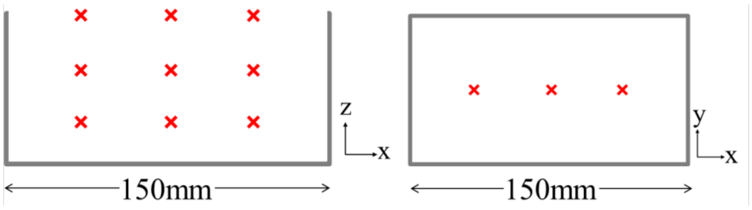

Figure 5. Approximate locations of the embedment inside of the CFT specimens

Because the movements of the screws are constantly recorded during the test it is also possible to calculate the rotations of the screws from the changes of their length in the images. However, the focus of this study is only on the movements in the x-z plane.

4 MATERIALS, SPECIMEN PREPARATION AND TESTING

In order to investigate the impact of the roughness of the bottom surface on the flow behavior of asphalt mixtures for wearing course, two mixture types with different aggregates structures with NMAS of 11mm were chosen: stone mastic asphalt (SMA) and asphalt concrete (AC). SMA normally has a higher percentage of coarse aggregates than AC. The SMA is mostly used for high traffic roads and highways whereas the AC is commonly used for local streets where the traffic loading is not very high. In this study, the percentage of aggregate sizes between 4 and 11mm for the SMA11 and AC11 mixtures were 70% and 42% of their total weights respectively. The bitumen type used for the mixtures was 70/100pen; based on the mix design, the binder contents of the mixtures were 6.4% by weight for SMA11 and 6.5% by weight for AC11.

Two identical aluminum molds were used for the tests. As mentioned in literature, e.g. Bahia et al. (2001), a lift thickness between 3-5 times the NMAS is recommended for an effective compaction. For achieving the desirable thickness in the field, pavers initially place the asphalt layer with 20-30% higher lift thickness; hence, the lift thickness of 50mm was chosen for the tests.

In order to prepare the molds, two geometrically different surfaces were used and mold heights were adjusted accordingly, providing an empty space of 150x100x50mm^3 for the mixture as shown in Figure 6.

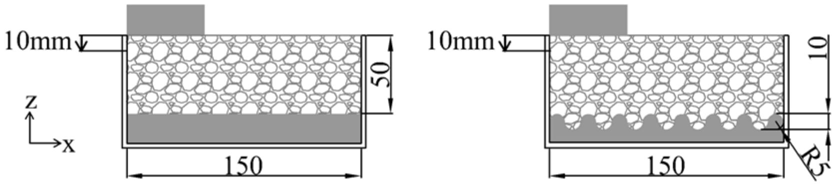

Figure 6. Flat and rough bottom surfaces used in this study (all dimensions are in mm)

For preparing each specimen, first, the mixture was heated up and then gently placed in three steps allowing positioning the screws as schematically shown in Figure 5. After that, the specimen was placed in the oven at compaction temperature 140°C for almost 2 hours for achieving a uniformly distributed temperature throughout the specimen. Note that, all specimens were filled with the same amount of mixture.

The imposed displacement for each CFT was 10mm, see Figure 6, with the loading rate of 15mm/min.

For each of the two mixture types used in this study, six CFTs were carried out, i.e. 3 on each bottom surface, resulting in 12 tests in total. Two examples of the images obtained at the end of the tests are shown in Figure 7.

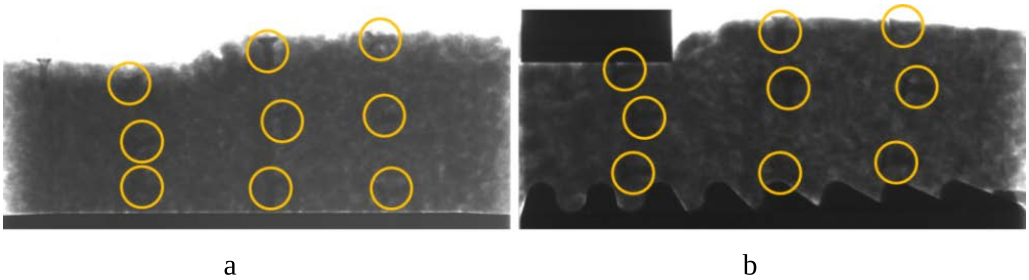

Figure 7. Examples of the acquired 2D X-ray images; (a) AC with flat and (b) SMA with rough bottom surfaces

5 RESULTS

In order to study the maximum impact of the compacting load on the specimens during the CFT, the final forces when reaching 10mm of displacement as well as the relative movements of the screws as compared to their initial locations are presented and discussed below.

5.1 Load versus displacement

As shown in Figure 7, the SMA mixtures with higher percentage of coarse particles required higher forces for the same imposed displacement than AC. However, for both mixtures, the required forces for imposing the same displacement were lower for the specimens with the rough than with the flat bottom surface. This is due to the fact that the initial volume was different and therefore the density of the mixtures after the compaction, see Figure 6. As compared to the specimens with the flat bottom surface, the required force for the SMA specimens was reduced about 50% and about 40% for the AC ones.

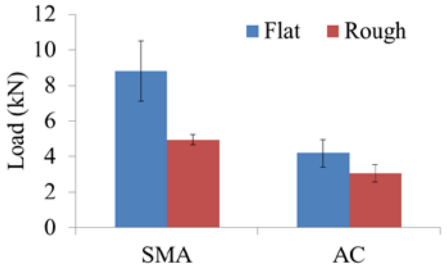

Figure 7. The mean values of the required forces and their standard deviations for obtaining imposed displacement

5.2 Image analysis and flow results

In order to analyze the acquired images to obtain the x-z movements of the screws, the first and the last images obtained before and right after imposing the compacting load were used. In order to disregard the rotation of the screws, it was decided to find the center coordinate of each screw before and after the test in the x-z plane and compare them. In this way a rough estimation of the movements at different locations of the specimens was obtained. Figure 8 shows the method used for obtaining the x-z plane movements of the embedded screws.

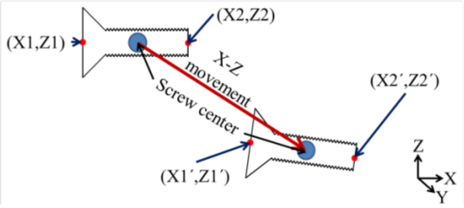

Figure 8. Schema of how the movement of each screw was obtained

As shown in Figure 9, regardless of the bottom surface geometries, the overall movements within the SMA specimens appeared to be larger than for AC which contains relatively fewer coarse aggregates than SMA.

From Figure 9 follows that the SMA mixtures, produce higher overall movements in case of flat bottom surface than with rough surface. For screw no. 1 under the loading strip, the movement is more vertical than for the flat surface. On the other hand, according to screw no. 4, the direction of the flow is the same for both surfaces; the movements of screw no. 7 indicates that the flat surface seems to cause a flow almost twice as large as with the rough bottom surface. On the load free side of the SMA specimens the directions of the flow seem to be mostly alike, except for screw no. 3, but the flow for the specimens with flat bottom surface appears still of higher magnitude. Such differences in the magnitude of flow show that the chosen roughness has had a preventive effect on the amount of flow but did not disturb the direction of the flow significantly.

For the AC mixtures (Figure 9), the major differences between the movements of the screws have occurred under the loading strip. Obviously, the overall movements under the loading strip, screws no. 1, 4 and 7, are more vertical for AC specimens with rough bottom surface than with the flat bottom surface. This also appears to be more substantial than for SMA specimens, suggesting higher impact of the chosen roughness on the flow of AC mixtures under the loading strip than with the SMA. Similar to the SMA specimens, the directions of the flow on the load free side of the AC specimens, i.e. screws no. 5, 6, 8 and 9, were similar regardless of the two bottom surfaces, however, the magnitude of the movements were affected by the roughness.

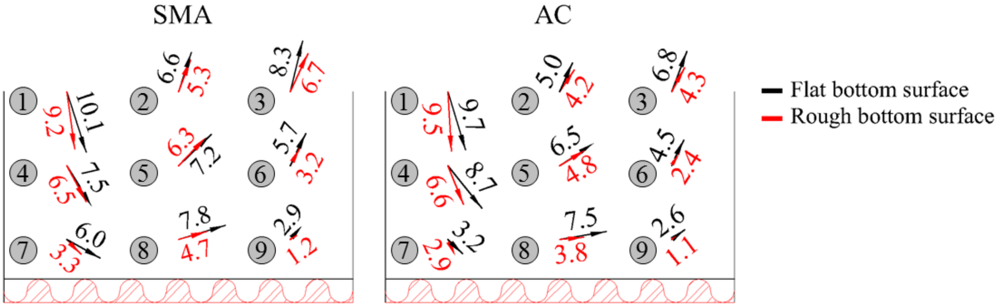

Figure 9. The mean values of the movements within the SMA and AC specimens with flat and rough bottom surfaces

The uplifts alone, as shown in Figure 9, reasonably reflect the internal flow within the specimens compacted on the chosen bottom surfaces which may be important for practice. The overall results indicate that using the CFT along with the monitoring system suggested in this study has a potential to reveal the internal changes of different mixtures compacted on surfaces with different roughness geometries. This might also help in finding optimized bottom surfaces for a better interaction between the overlay and its bottom layer on the roads.

6 CONCLUSIONS

Based on the obtained results in this study the following conclusions can be made:

- The CFT setting along with the suggested X-ray imaging appeared to have a good potential for studying the internal flow behavior of asphalt mixtures with different characteristics on surfaces with different roughness geometries.

-This method may help in finding optimized bottom surfaces for a better interaction between the overlay and its bottom layer on the roads.

- The Mixture with higher portion of the large aggregate size fractions, i.e. SMA in this study, appeared to demonstrate higher overall flow regardless of the geometry of the bottom surface that it is compacted on.

- The overall movements and flow within the specimens compacted on flat bottom surface appeared to be higher as compared with the ones compacted on the chosen rough bottom surface.

- The overall flow directions right under the loading strip down to the bottom surface appeared to be more vertical for the ones compacted on the rough bottom surface. However, the direction of the flow on the load-free side of the specimens appeared to be aligned but higher in magnitude for the mixtures compacted on the flat surface.

- The results suggest that the internal flow differences between asphalt mixtures compacted on the different bottom surfaces can be distinguished solely by comparing their uplifts.

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