LABORATORY PRODUCTION OF LARGE-SIZED ASPHALT SPECIMENS

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ABSTRACT

Future asphalt performance tests are likely to require much bigger specimens than those being used at present. The production of large-sized asphalt specimens is essential for advanced dynamic testing methods such as the four point bending test according to DIN EN 12697-24/-26. A maximum aggregate size of 32 mm leads to a specimen size of 96 x 96 x 576 mm. Right now there is no such laboratory compactor commercially available to produce specimens of that size.
Consequently it is necessary to develop a new laboratory compactor. To get an understanding how conventional laboratory compaction works the production routine of the asphalt roller compactor located at the asphalt laboratory of the University of Wuppertal was analyzed. The influence of each stage of production – the filling procedure by different laboratory personnel (initial compaction), the compaction degree after pre-compaction and main-compaction – was determined. Further focus was being put on the homogeneity of the produced asphalt slabs after each stage of production by cutting each slab into prisms of 60 x 60 mm to determine their density.
Current asphalt compactors for the production of normal-sized asphalt specimens are standardized in DIN EN 12697-33. The production of large-sized asphalt specimens asks for new developments to ensure the production of uniform specimens regarding both 2D and 3D homogeneity. For the development of a new asphalt roller compactor for large-sized asphalt specimens the production steps filling/distribution of hot asphalt and pre-compaction were modified to simulate a fully automated processing close to an in-situ compaction.

Keywords: large-sized specimens, asphalt roller compactor, homogeneity, slabs, influences to laboratory compaction

1. INTRODUCTION

Long lasting asphalt pavements require mixtures that have been laboratory tested and proven before. The results of these laboratory tests are highly depended on the compaction method used to produce asphalt specimens. Therefore it is important to adjust laboratory compaction as far as possible to the in-situ compaction.

Furthermore, there is a need for large-sized asphalt specimens. This is based on the fact that dynamic testing methods such as the four point bending test according to DIN EN 12697-24 [1]/-26 [2] require specimens (prisms) of up to 576 mm length if the asphalt contains a maximum aggregate size of 32 mm. Furthermore it is essential to produce homogeneous specimens – e.g. drilling cores – taken out of one single homogeneous slab at best.

Since there is no laboratory compactor commercially available to produce specimens of that size it was necessary to develop a new roller sector compactor based on the widely-used "German roller sector compactor" according to TP Asphalt, part 33 [4] (see figure 1). The German standard TP Asphalt, part 33 evolved from DIN EN 12697-33 [3]. The new developed roller sector compactor is able to produce specimens of 820 x 260 x 240 mm size with new key features such as a fully automated distribution of hot mix asphalt and a new way of pre-compaction of the hot mix asphalt.

Before the new roller sector compactor was built, the status-quo of the existing "German roller sector compactor" was analyzed to introduce improvements into the new roller sector compactor. Therefore each step of production, such as the filling procedure, the pre-compaction and main compaction was investigated closly.

The following paper is a preliminary result of a research project [9] which is being conducted between 2010 and 2012.

Figure 1 : Widely-used "German roller sector compactor" for specimens 320 x 260 x max. 120 mm

2. MATERIAL

Due to the large amount of hot mix asphalt needed to produce large sized asphalt specimens throughout the project, the decision was made to acquire hot mix asphalt from a mixing plant. Two mixtures – a stone mastic asphalt (SMA 11 S) and an asphalt concrete (AC 16 B S), both with polymer-modified bitumen – were delivered with an asphalt-thermo-container and filled into tin buckets. For further analysis the tin buckets were numbered in sequence to their filling. The total amount of more than 16000 kg (ca. 1000 tin buckets) ensures the material supply for the production of all specimens over the course of the project. All specimens will be produced from one sample (population) which is important for statistical conclusions.

The material parameters from the initial type testing are as follows:

Table 1 : Material parameters

	SMA 11 S	AC 16 B S
maximum density of hot mix asphalt [g/cm³]	2,509	2,612
Bulk density of MPK [g/cm³]	2,439	2,468
Void content [%]	2,8	5,5
Binder / modifier	PmB 10/40-65 A / elastomer	PmB 10/40-65 A / elastomer
Aggregates	Diabase	Diabase

In order to control the homogeneity of the asphalt for each produced slab two Marshall Specimens were produced and their bulk density was determined. During the project the compaction degree of each produced slab was related to the bulk density of these Marshall Specimens. This approach represents an indirect, yet a time-saving method to draw conclusions on the homogeneity of the delivered asphalt. In addition to the determination of the bulk density the maximum density of the asphalt was measured by random sampling. This approach was necessary since it would have been too much of an effort to determine the maximum density of the asphalt of all 1000 tin buckets. Therefore a total of 26 tin buckets were randomly chosen to get further information on the maximum density in addition to the information of the initial type testing. The results of the determination of the maximum density of the asphalt can be seen in table 2.

Table 2 : Maximum density of hot mix asphalt, N=26

maximum density of hot mix asphalt [g/cm³]	SMA 11 S	AC 16 B S
Initial type testing	2,509	2,612
Random sampling, median	2,523	2,604
Random sampling, arithmetic average	2,523	2,609
Random sampling, standard deviation	0,007	0,017

Figure 2 and figure 3 show the summary of a total of 280 produced Marshall Specimens from about 140 tin buckets so far. There is a higher standard deviation for the asphalt concrete due to the bigger maximum aggregate size of 16 mm which leads to a certain segregation process while handling the material. This is a first indication for the importance of homogeneity for the production of asphalt specimens in general, large-sized asphalt specimens in particular.

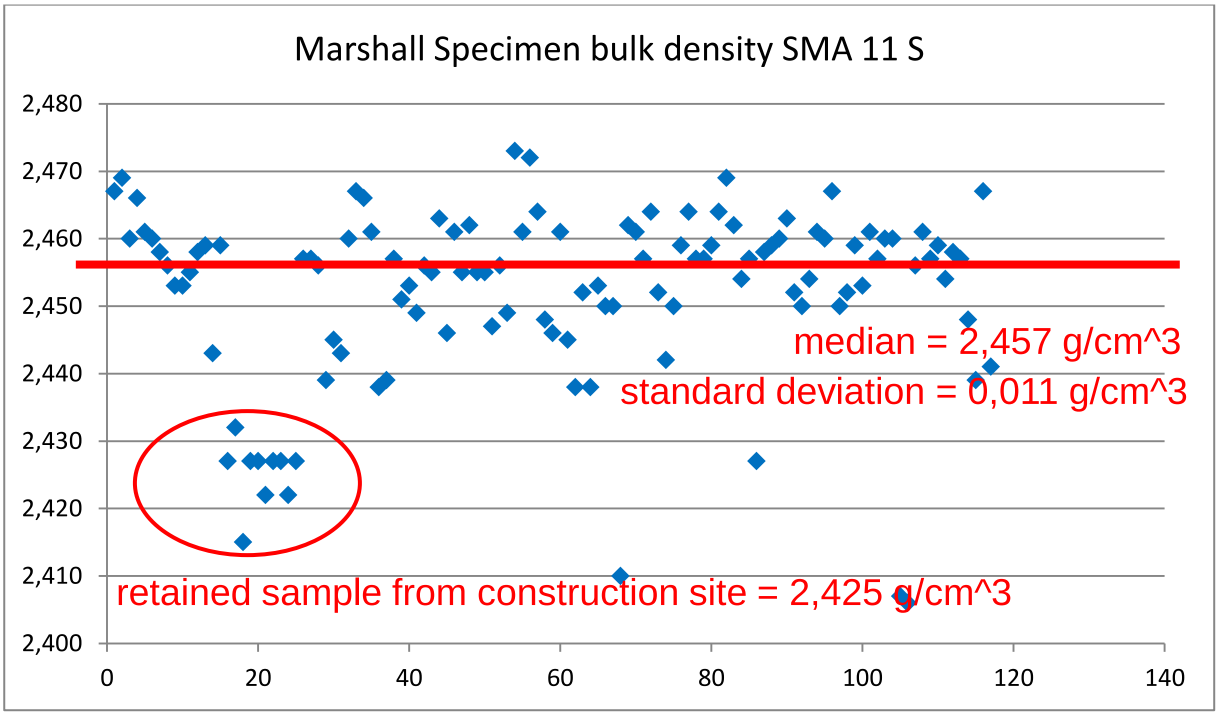

Figure 2 : Overview bulk density of Marshall Specimen – SMA 11

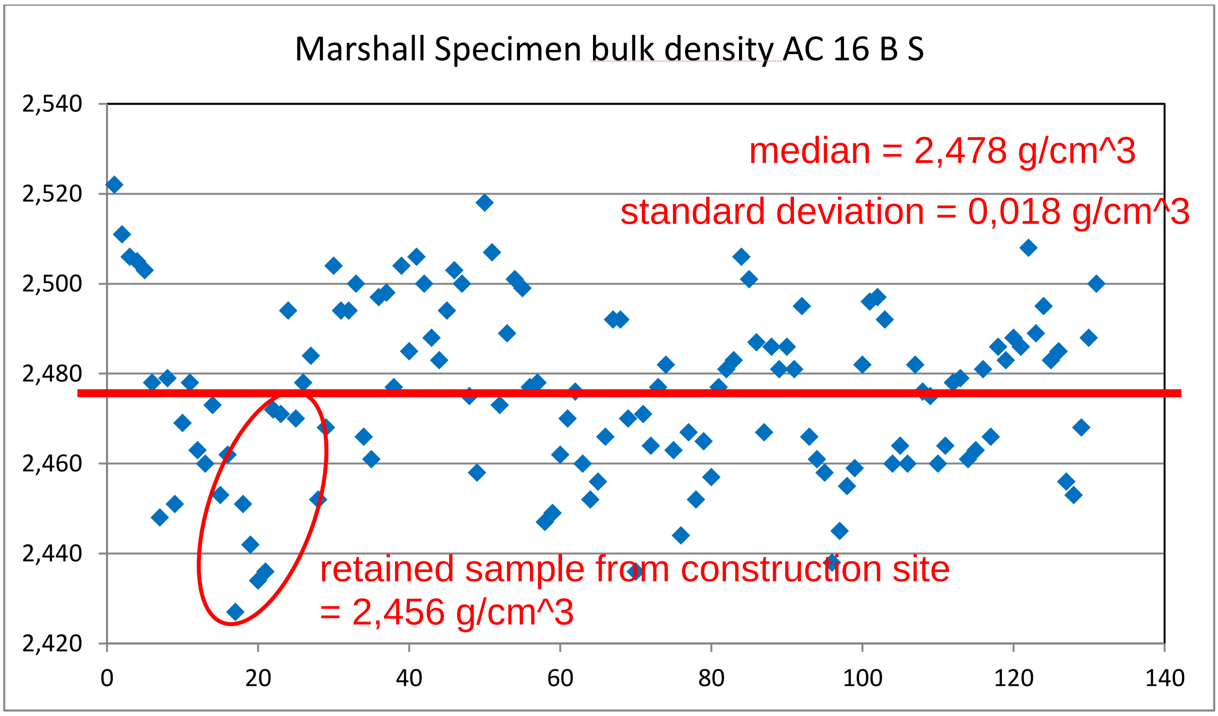

Figure 3 : Overview bulk density of Marshall Specimen – AC 16

3. RESEARCH PROGRAM

The first part of the research program considering the status-quo of the existing "German roller sector compactor" was structured into two main areas - the analysis of the pre-compaction and the analysis of the main-compaction. The compaction method of the „German roller sector compactor" - the so called "combined force-displacement-procedure" - is described in TP Asphalt, part 33 [4]. It is based on a displacement-controlled pre-compaction and a force-controlled main compaction. Figure 4 illustrates the separate steps of this compaction method:

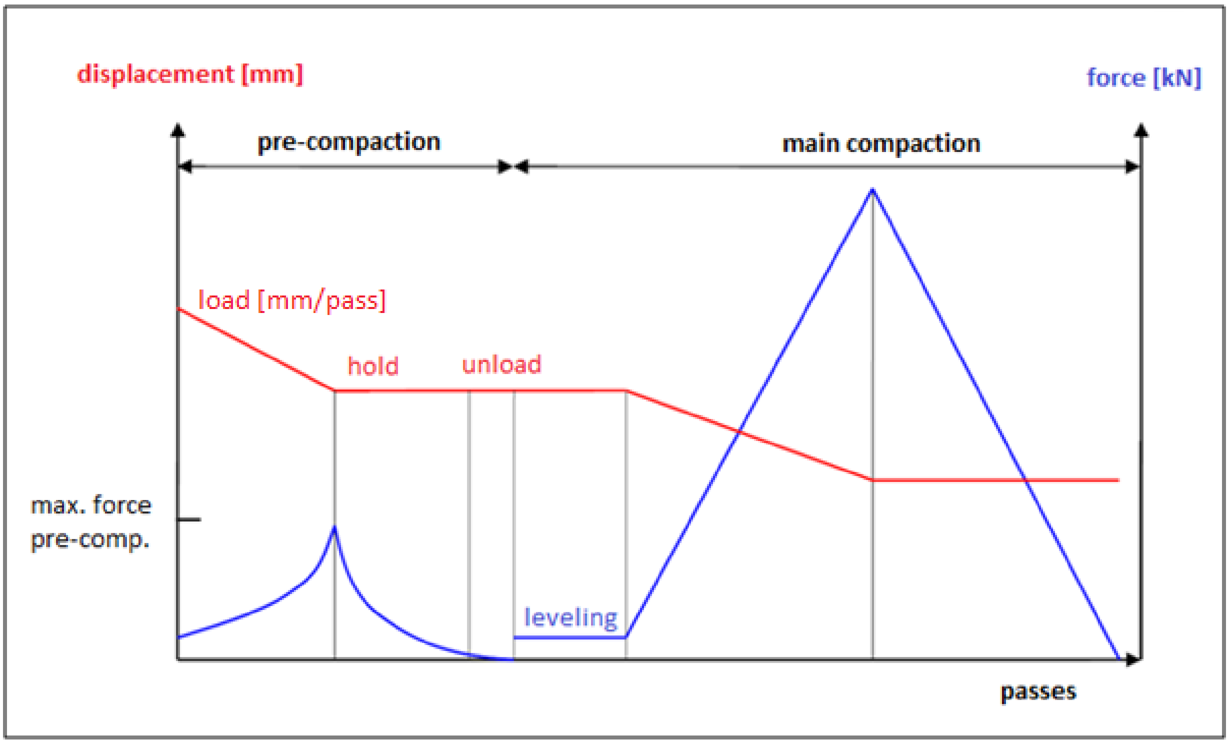

Figure 4 : German roller compaction method "combined force-displacement-procedure" according to TP Asphalt, part 33 [4]

Based on the existing „German roller sector compactor“ and its compaction method, the first part of the research program breaks down to the following parts:

Pre-compaction:

1. initial compaction
   - analysis of the filling procedure of the hot mix asphalt
   - just filling in and distribution of the hot mix asphalt
   - no machine compaction
2. pre-compaction according to the compaction program described in TP Asphalt, part 33 [4]
   - pre-load: a number of displacement controlled (0.5 mm/pass) roller passes up to a max. force of 2,6 kN
   - holding displacement: five roller passes with no change in height – maintaining the slab thickness
   - unload: a number of displacement controlled (0.5 mm/pass) roller passes until the force is completely removed
3. testing of a new technique for the leveling of the asphalt surface using a metal plate (ductor, see figure 8)
   - analysis of the leveling procedure of the hot mix asphalt
   - no machine compaction
4. simulation of a tamping pre-compaction using a metal plate on top of the leveled hot mix asphalt (see figure 13)
   - tests with forces between 5 kN and 20 kN

Main compaction:

1. main compaction according to the compaction program described in TP Asphalt, part 33 [4]
   - pre-compaction according TP Asphalt, part 33 as described above (pre-compaction, step 2), plus:
   - smoothing: 15 force-controlled roller passes with a force of 0,52 kN
   - compaction: 15 force-controlled roller passes with an equal increase in force up to a maximum of 19,5 kN
   - unload: 15 force-controlled roller passes until the force is completely removed
2. main compaction displacement controlled (specimen height is the target value, roller sector moves 0.5 mm/pass. Compaction degree aimed at 99 - 101 %)

The pre-compaction steps were split up in those tests conducted by distributing the hot mix asphalt manually (as described in TP Asphalt, part 33 [4]) and those tests using a metal ductor to simulate a semi-mechanical distribution of the asphalt. Those specimens that were produced by a manual distribution of the material were done by different laboratory personnel (N = 3) to study the influence of a human factor on the process.

Different tests were performed to determine the influence of each production steps, such as the Wheel Tracking Test TP Asphalt-StB, part 22 [5], the determination of the resilient modulus DIN EN 12697-26 [2] and the dynamic pressure threshold test TP Asphalt-StB, part 25 B1 [6]. About 40 slabs were tested this way.

The homogeneity was determined by cutting slabs of every single pre-compaction and main compaction step into prisms of 55 x 55 mm size. Therefore each slab gave 20 prisms that were then used for determining the bulk density according to TP Asphalt-StB, part 6 [7]. A total of 1300 prisms were measured for their bulk density.

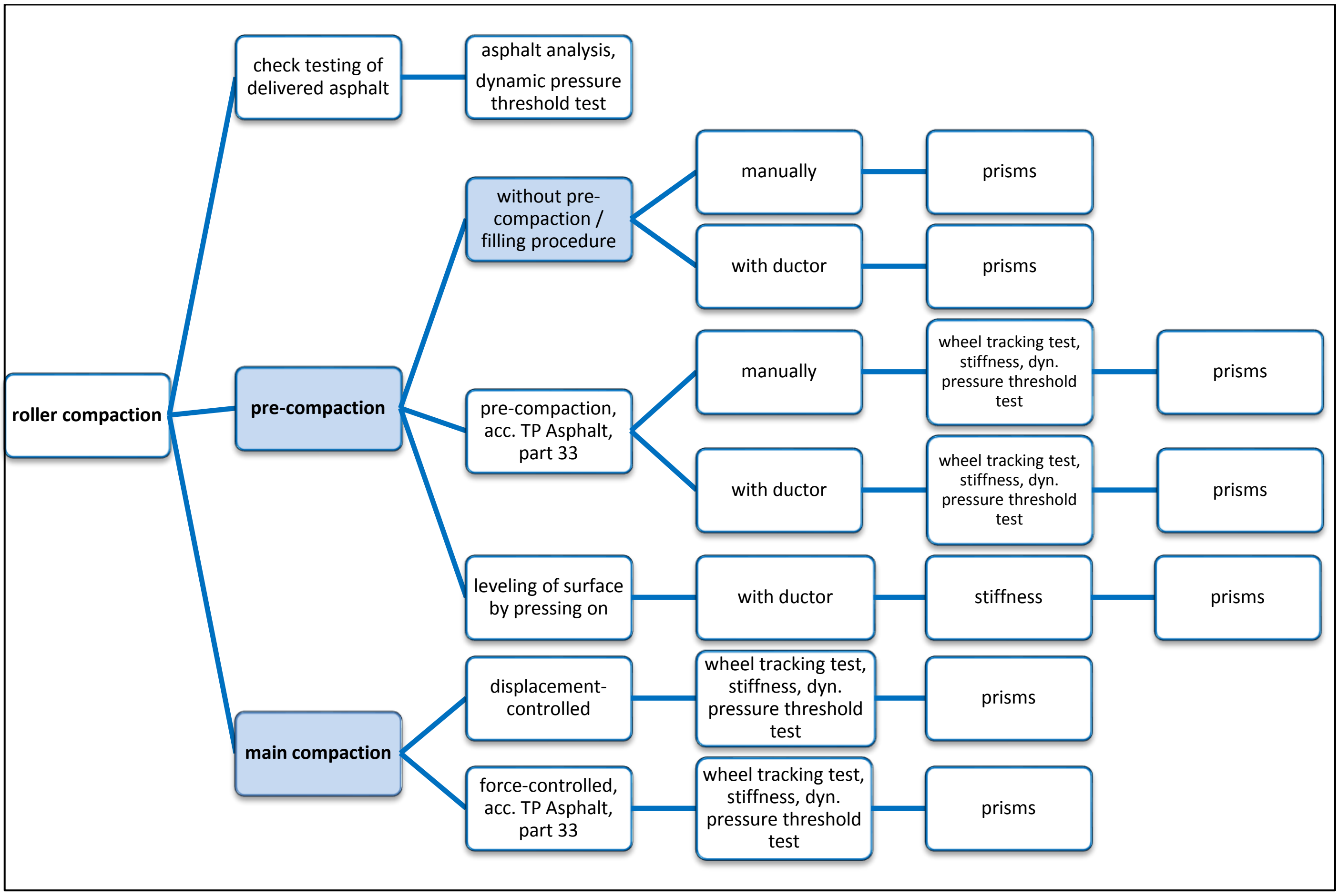

Figure 5 : Structure of the research program

3.1 Bulk density of prisms

Each slab was cut into prisms of 55 x 55 mm in four rows and five columns according to figure 6:

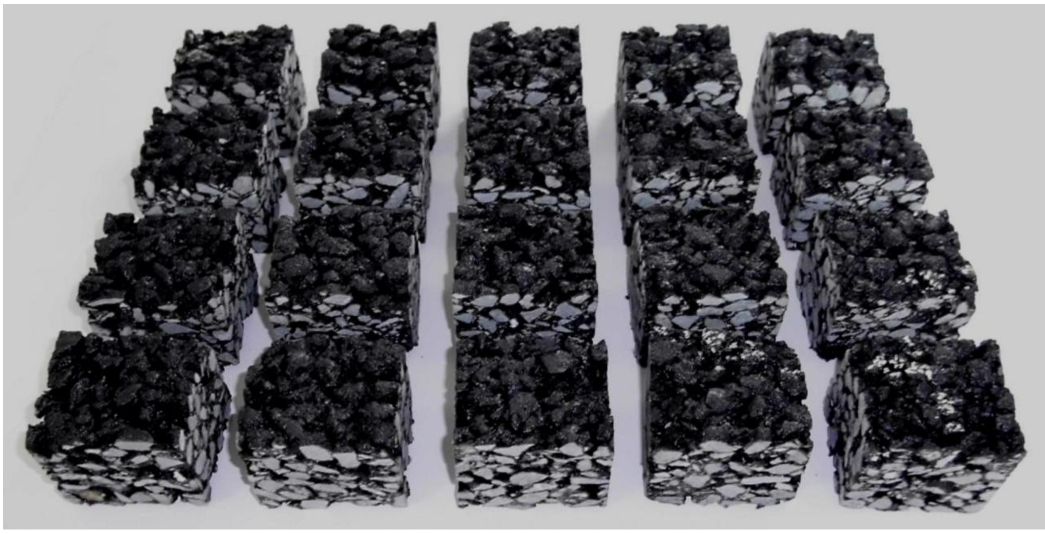

Figure 6 : Cutting layout of prisms (here: slab without compaction)

For further interpretation the bulk densities were diagrammed and statistical grouping was performed. The absolute difference between the bulk densities and the median of the bulk densities of each slab was calculated and sorted into five classes (see figure 7). In this way deviations to the homogeneity could visually be assessed.

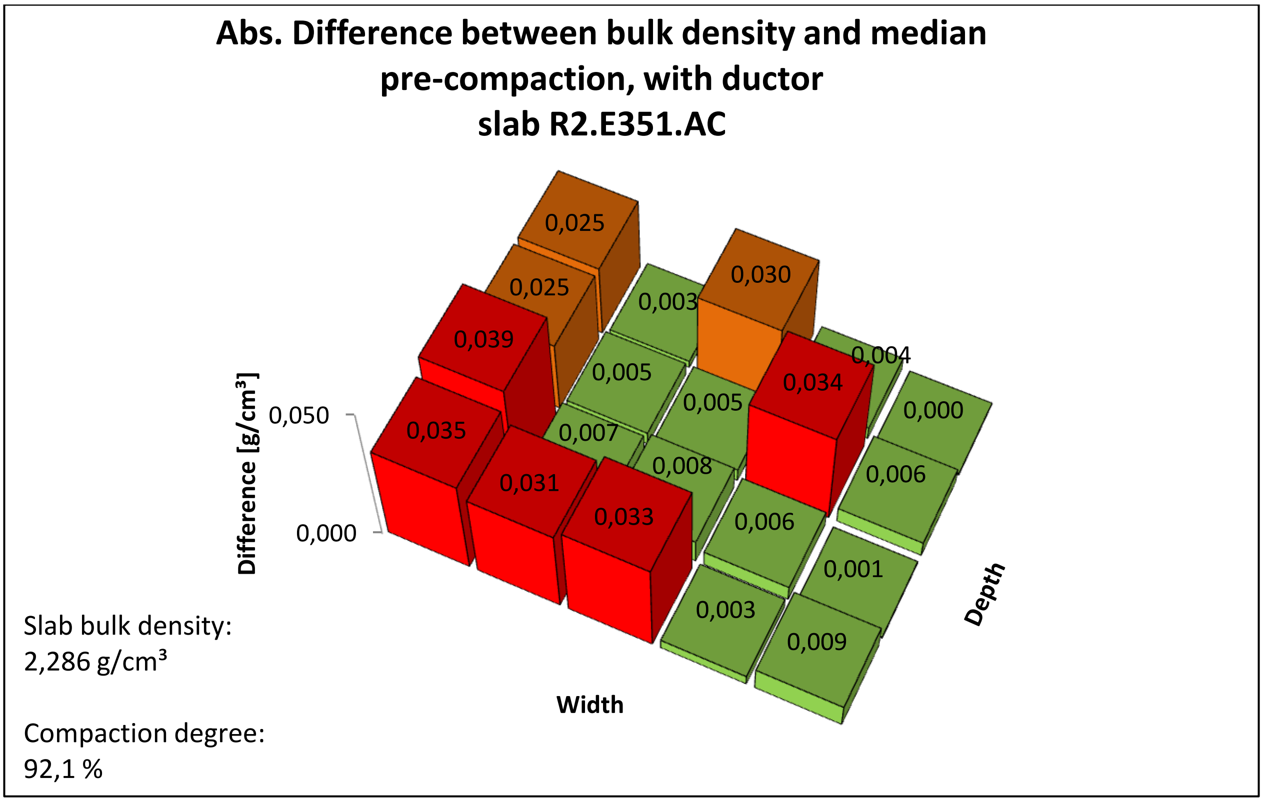

Figure 7 : Example of an interpretation of the gained bulk density data (here: absolute difference of the bulk density to the median)

3.2 Leveling of the asphalt after filling in

According to TP Asphalt-StB, part 33 [4] the hot mix asphalt is to be filled into the metal form and to be leveled out manually using a spatula. This process is influenced by a human factor. This research project aimed at determining this human factor and finding ways to automate this process to reduce the human factor.

Therefore three different experienced laboratory personnel produced several slabs just by filling in the hot mix asphalt and leveling it without starting the compaction process afterwards. The uncompacted slabs were removed from the mould and cooled down. Afterwards the bulk density was determined and the slabs were cut into prisms according to chapter 3.1.

These results were compared to a semi-mechanic process using a ductor (metal plate) as displayed in figure 8.

Figure 8 : Ductor (metal plate) for semi-mechanic leveling of hot mix asphalt

The ductor was used a certain way to establish a standard way of leveling. The asphalt was poured in the middle of the form cone-shaped and the ductor was lowered in the middle of the cone (height: X). Then the ductor was pulled to the right side of the form to move a major part of the asphalt and then again from the middle to the left side. Afterwards the ductor was adjusted slightly higher (height: X+Y) and moved from the sides to the middle to dispense the asphalt on the surface.

The influence of a manual leveling of the filled in hot mix asphalt compared to a semi-mechanic leveling using a ductor (metal plate) concerning the bulk density of the cut prisms can be seen in table 3. The median of the manually leveled asphalt is about 89 % for the stone mastic asphalt and about 1 % less for the asphalt concrete. The semi-mechanic leveling results in slightly higher bulk densities of about 1 % to 2 %. A possible reason for a higher bulk density could be the circumstance that the semi-mechanic leveling is more intense than the manual leveling – since more material is being moved initially from the middle to the sides. The rather high standard deviation of 3,8 % for the stone mastic asphalt and the semi-mechanic leveling is expected to be lowered as the leveling becomes fully automated.

Table 3 : Comparison of manual and semi-mechanic leveling of hot mix asphalt regarding the bulk density

Variant	Compaction Degree	SMA 11 S	AC 16 B S
manual leveling	standard deviation	0,5 %	0,4 %
	median	89,0 %	88,1 %
semi-mechanic leveling	standard deviation	3,8 %	0,5 %
	median	90,9 %	89,0 %

Those slabs being leveled using the ductor show an even surface and the same height over the whole area. This can be seen at figure 11. This is important for large-sized slabs as a manual leveling of the hot mix asphalt becomes less accurate.

Figure 11 : Stone mastic asphalt (without compaction) with an even surface, leveled using a ductor

3.3 Pre-compaction

In-situ pre-compaction differs widely from pre-compaction by the roller sector compactor in the laboratory. This is because of a different compaction behavior between the roller sector compactor (a tumbling compaction) and the paver screed plate of the paver in the field (a tamping compaction) as displayed in figure 12. This difference in pre-compaction leads to a different orientation of the aggregates within the asphalt. Therefore it is important to adjust the pre-compaction to the situation in the field. To simulate a tamping compaction with the existing roller sector compactor in the laboratory a metal plate was put on top of the yet un-compacted, leveled hot mix asphalt according to figure 13. The sector was moved on top this plate and pushed with different forces. Afterwards the compaction degrees of these pre-compacted slabs were determined. The average compaction degree was 90,4 % at 10 kN force.

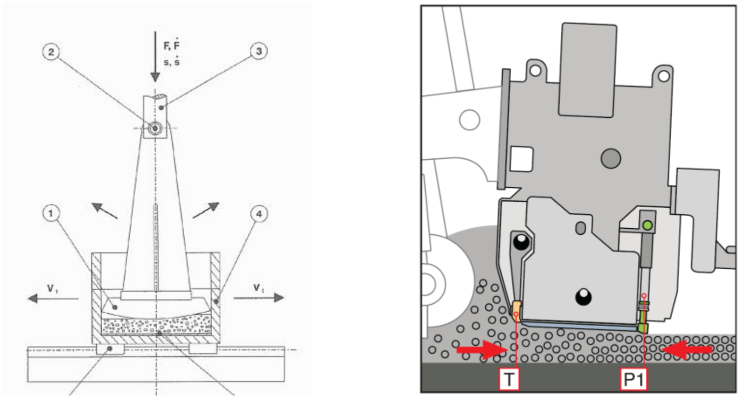

Figure 12 : tumbling compaction (figure left, roller sector compactor [4]) and tamping compaction (figure right, paver screed plate, [10])

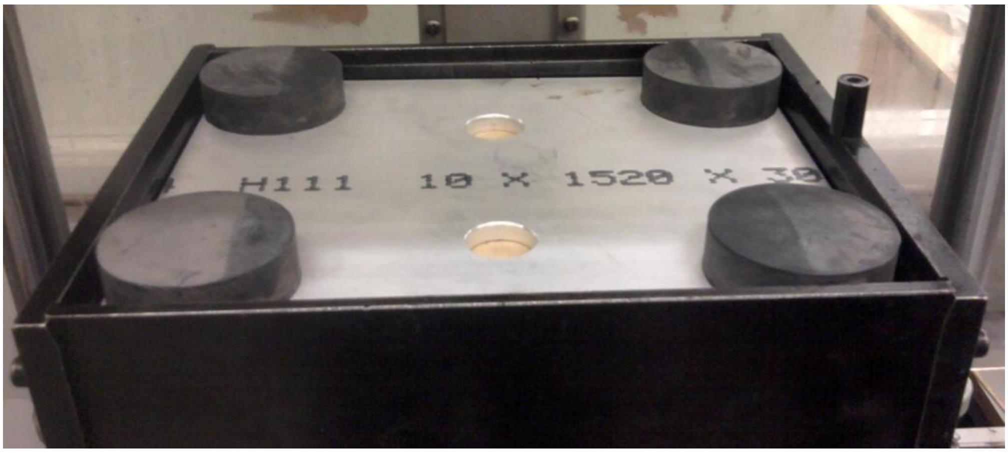

Figure 13 : Metal plate on top of leveled hot mix asphalt to simulate a tamping pre-compaction

A smooth and even surface builds the basis for a homogenous slab. The existing compaction method according to TP Asphalt, part 33 [4] in combination with the manual leveling of the asphalt might lead to inhomogeneity of the slabs as the tumbling compaction of the roller sector is done on top of the un-compacted asphalt surface. If the hot mix asphalt is not perfectly leveled, the following compaction might result in higher bulk densities where there is more material and lower bulk densities in parts with less asphalt.

The testing of the features like distribution and leveling of the hot mix asphalt with a ductor and a pre-compaction without a tumbling movement of the roller sector was introduced into the development of the prototype of a roller sector compactor.

4. CONCEPTION OF THE PROTOTYPE

The main body of the machine is limited to a width of 95 cm and a height of 195 cm due to the size of average laboratory rooms. Taking into account the maximum weight of about 3 tons for the whole machine, it is possible to have a machine base of maximum 1.6 tons, thus it is built as a lightweight construction. The concept is designed to have the left side of the machine for filling the mould box and removing the rolled sample and the right side for the roller sector.

The rolling segment is a main component of the compactor (see figure 14). For the standard slabs of 320 or 410 mm length it is common to produce the rolling segment in two steps, which means a massive steel segment connected with a screw-on mounting flange. Experience with this type of construction showed that the accuracy of the rolling segment attainable with this approach is relatively low. If this construction was to maintained, the roller segment would either be inaccurate or the production would become extremely complex and expensive. The weight of the machine would also increase by a factor of five, making the machine dynamics (i.e. the control quality the force and the position control of the Y-axis drive) less desirable. To avoid this problem, the new roller segment has been executed as a light welded construction with subsequent mechanical processing of the bottom of the segment. This approach also provides much more flexibility to the design of the heating system which was previously built with a silicone heating mat. Thus, the maximum possible heating power was limited by the area and specific heating capacity. Due to the massive construction of the rolling segment in the past it was difficult to control the temperature, strong overshoots were the result. With the new, light-weight construction the above mentioned problems are going to be reduced significantly. The period of heating will be much shorter (about half the time). Instead of a heating mat an infrared heater is being used, which promises a better control quality in spite of a higher specific heating capacity. Furthermore the heating system will be improved by measuring the bottom of the roller segment with an infrared thermometer contactless. The sensor is installed stationary at the upper part of the machine base.

Figure 14 : Fully automated ductor (left side) and light welded roller sector with infrared heating (right side)

A completely new heating system was developed for the mould box. Instead of heating the bottom part of the mould box a heating element is placed into the mould box from above, which preferably heats the side walls of the mould box (see figure 15). Shortly before the filling of the mould with hot mix asphalt, the heating device is lifted up into a parking position. The new method to only heat the walls of the mould box is much more effective and is closer to the situation in the field (hot surroundings, rather cold base). In the past, the mould box side walls were only heated indirectly by the bottom plate. As a result the control quality for this process was rather poor and the temperature distribution could not be influenced.

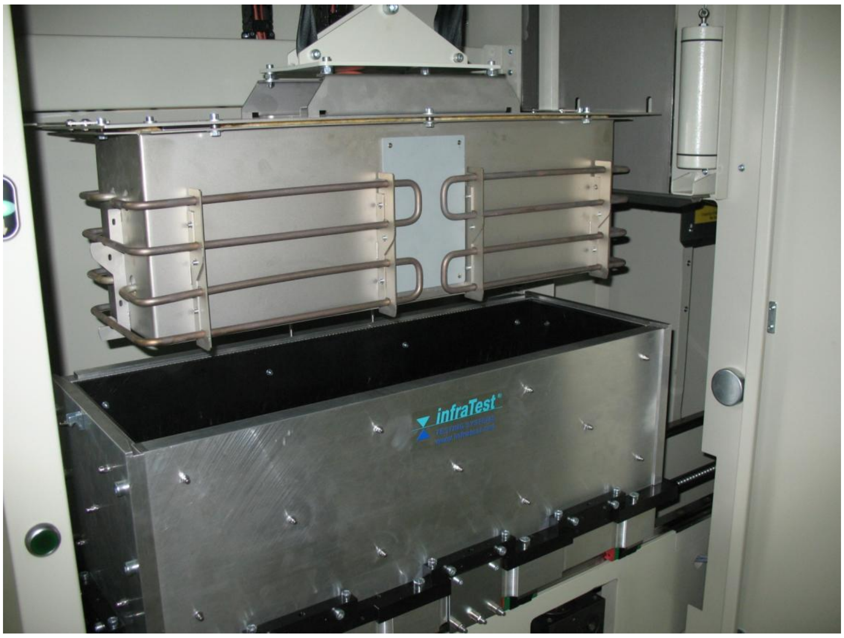

Figure 15 : Mould box and new heating device for heating side walls of the mould box

The key features of the new developed roller sector compactor are listed below:

- roller sector with infrared heating (high control quality)
- indirect heating of the mould box – heated side walls of the mould box (close to reality)
- fully automated leveling of the hot mix asphalt by a ductor (freely programmable)
- realistic static pre-compaction by sequential lowering of the roller sector

4.1 Current Research

As stated before, the development of the new roller sector compactor for large-sized asphalt specimens has not been finished yet. The prototype is located at the University of Wuppertal at the Pavement Research Centre since October 2011 (figure 16). Since then, it is being tested intensively to develop and optimize the production steps filling in and leveling of the hot mix asphalt by an automated ductor program, the pre-compaction by sequential lowering of the roller sector and the main compaction with a program which will represent the in-situ compaction as close as possible.

To ensure an in-situ compaction situation the asphalt specimens will be tested for their bulk densities, the orientation of the aggregates using iPas-2 software [8] and overall performance. Final results are expected for the end of 2012.

Figure 16 : New roller sector compactor for large-sized asphalt specimens

5 CONCLUSIONS

The preliminary results of this research project clearly show that the quality of asphalt specimens is highly dependent on each single step of the production-procedure and not only on the main compaction. Most important are the distribution and the leveling of the hot mix asphalt in the mold, the pre-compaction method and the control quality of force and position of the sector drive. There is further a fundamental influence like the way to heat the mould box (the standard EN-12697-33 does not require a heating device of the sector and the mould box at all). If those boundary conditions are taken into account, it is possible to produce large-sized asphalt specimens with properties close to asphalt in-situ.
After all the roller sector compaction is a widely-spread method to produce asphalt specimens for performance based laboratory tests. The newly developed roller sector compactor ensures a progress in producing these asphalt specimens concerning the dimensions and the homogeneity of the bulk density.

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