

Construction of experimental HMA test sections in order to monitor the compaction process.

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ABSTRACT: For getting better understanding about the process of HMA compaction, a test section was constructed while the governing process parameters, like; compaction progress, temperature of the material at which activities were employed, equipment properties and meteorological circumstances, were monitored. The test section consists of two constructed layers divided in two lanes A and B. The different lanes were compacted at different temperatures and with a different number of roller passes. In spite of the fact that common asphalt practice suggests that material temperature affect mixtures compactibility, the test section results indicated that no relationship between temperature and compaction progress could be identified. Different measuring techniques to monitor compaction progress were compared.

KEY WORDS: Pavement, Compaction, Test sections, Material specifications.

1. INTRODUCTION

Quantitative knowledge about the material behaviour of Hot Mix Asphalt concrete (HMA) during compaction processes is hardly available. Therefore, it is difficult to understand quantitatively how road constructions with a homogeneous compaction level can be realised close to prescribed specifications, especially in case of adverse external circumstances (Huerne, 1997). Nevertheless sufficient compaction for HMA in road constructions is very important for realising a good bearing capacity and a high durability. The joint research project of Twente University and the Delft University of Technology aims to develop a generic tool that employs the Finite Element Methods (FEM) approach to simulate the compaction process of HMA. An overview of the research project is given in figure 1. The compaction test section is just a part of the research project. Construction of the test section and analysing the results is the main topic of this paper.

First the lay out of the constructed test section is discussed as well as the measurement programme. The second part presents the analysis of the results obtained. It was assumed that the material temperature and the progress in material compaction were the most important variables, therefore the paper focuses on these two items.

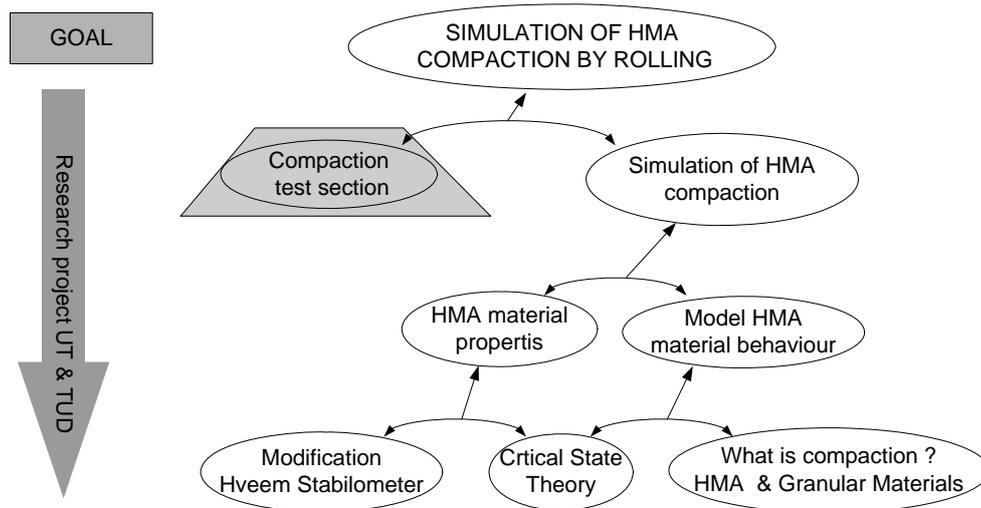


Figure 1: The set-up of the research project, shaded area is the topic discussed in this paper.

2. “LAY OUT” OF THE CONSTRUCTED TEST SECTION

2.1. Construction of a test section

The objective of the experimental compaction test section was to gather information in order to be able to validate the developed simulation tool for compaction of HMA. From road building practice it is known that material temperature is an important determinant of mechanical material behaviour. Therefore compaction of the HMA at different temperatures was implemented in the set up. The set up of the section was therefore organised as follows. The test section was divided into two parts; lane A and lane B. The different lanes were compacted with a different number of roller passes (16 for lane A and 8 for lane B) distributed equally over the same time period.

The temperature of the material during rolling, part (c) of Figure 2, could be achieved by combination of the relations illustrated in parts (a) and (b) of Figure 2 (respectively the distribution of roller passes during compaction and HMA cooling during compaction). The figure also helps to explain what data were measured. The distribution of the number of roller passes (a) in time and measuring the HMA cooling in time (b). Linking these information to each other (through the time variable) made it possible to determine the temperature at which the roller passes were applied (c).

The test section consists of two asphalt layers on an asphalt foundation. These layers were approximately 30 meters long and 2.70 and 2.50 meters wide respectively. The HMA was spread in two layers of each 50 mm¹ thick in compacted state. Figure 3 illustrates the details of the test section. On the test section 22 measuring points were selected where thickness, specific density, time and temperature measurements were taken. At 16 of these points the layer thickness during compaction was measured with both a level and rod and Strato test equipment. At four points the specific density was monitored with the nuclear Troxler apparatus, and at two points (lines) temperature and time measurements were taken. Figure 3 shows the locations of the measuring points.

At the end of the experiment cores were drilled at the 16 locations where thicknesses were measured. From these cores, final layer thickness and the specific density of the material were

obtained. Temperature of the asphalt was monitored by use of thermo couples inserted at three depths in the layer.

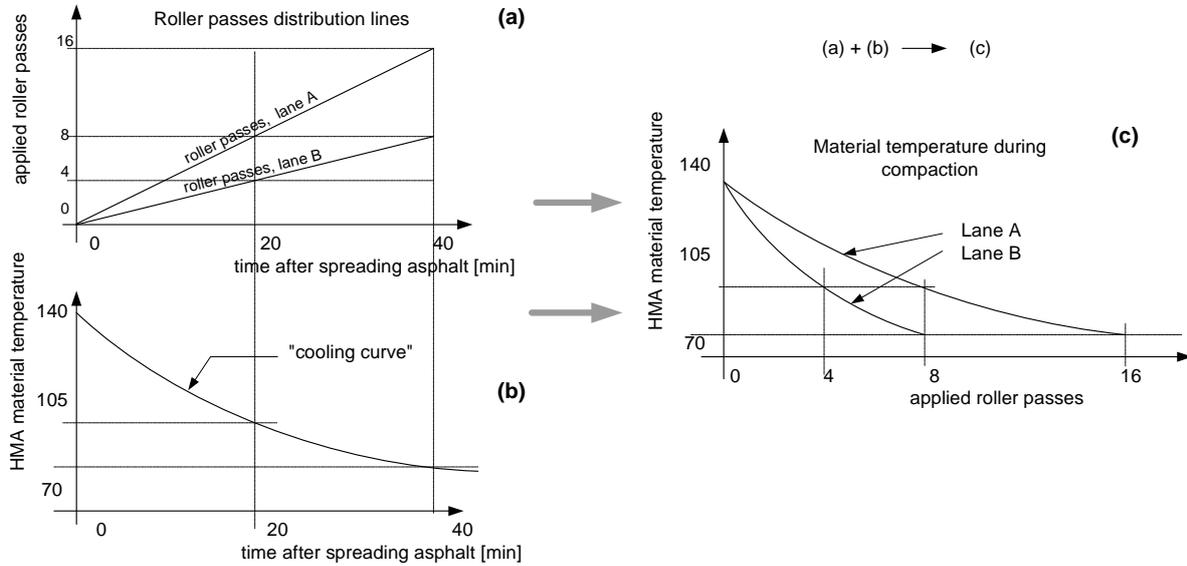


Figure 2: Linkage of rolling distribution lines to material cooling curves for achieving the rolling temperatures of lanes A & B.

2.2. Materials used and Equipment employed

For the compaction of the test section use was made of just one particular roller. The compactor used was a HAMM DV6.42. This type of compactor can be used in the static and in the vibration mode. Because simulation of HMA compaction is complex this research focuses solely on the development of a model to simulate the compaction of a roller in static mode. This roller was equipped with two identical drums of 1400 mm wide and 1100 mm diameter. According to factory specifications, the total weight of the roller was estimated to be 7.9 tons, equally distributed over both drums. The roller was a tandem roller. During compaction of the test section the drums were running in the same track. Hence, every roller pass counted for two roller drum passes. The equipment was actually weighed to obtain a more precise operating weight than the general factory specifications. The values obtained are presented in Table 1.

Table 1: The weights of the used roller.

Specifications of the Hamm DV 6.42; used operational mass distribution						
Front/Rear axle	Front + Rear		Front		Rear	
Water tanks	Full	Empty	Full	Empty	Full	Empty
Mass [kg]	7.240	6.600	3.620	3.300	3.570	3.260

The material used for construction of the two layers of the compaction test section was a mixture that conforms the Dutch Standard (CROW, 1995) for wearing courses; it was a Dense Asphalt Concrete (DAC) 0/16 with a maximum particle size of about 16 mm. A Dutch contractor designed a suitable material composition, produced the mix in a hot mix asphalt plant, paved and compacted the layers and took care of quality control during production.

The aggregate of the mixture was composed of;

- 59.8 % of coarse aggregate (> 2mm, all crushed)
- 33.6 % of sand (3 parts crushed on 1 part natural)
- 6.6 % of filler (< 63 μm)
- 6.2 % of a 80/100 PEN bitumen(on 100% by mass of aggregate)

By production checks on the involved material the Marshall density (2 times 50 blows) was obtained on 2375 kg/m^3 . The density of the mixture at 0% voids was obtained on 2416 kg/m^3 .

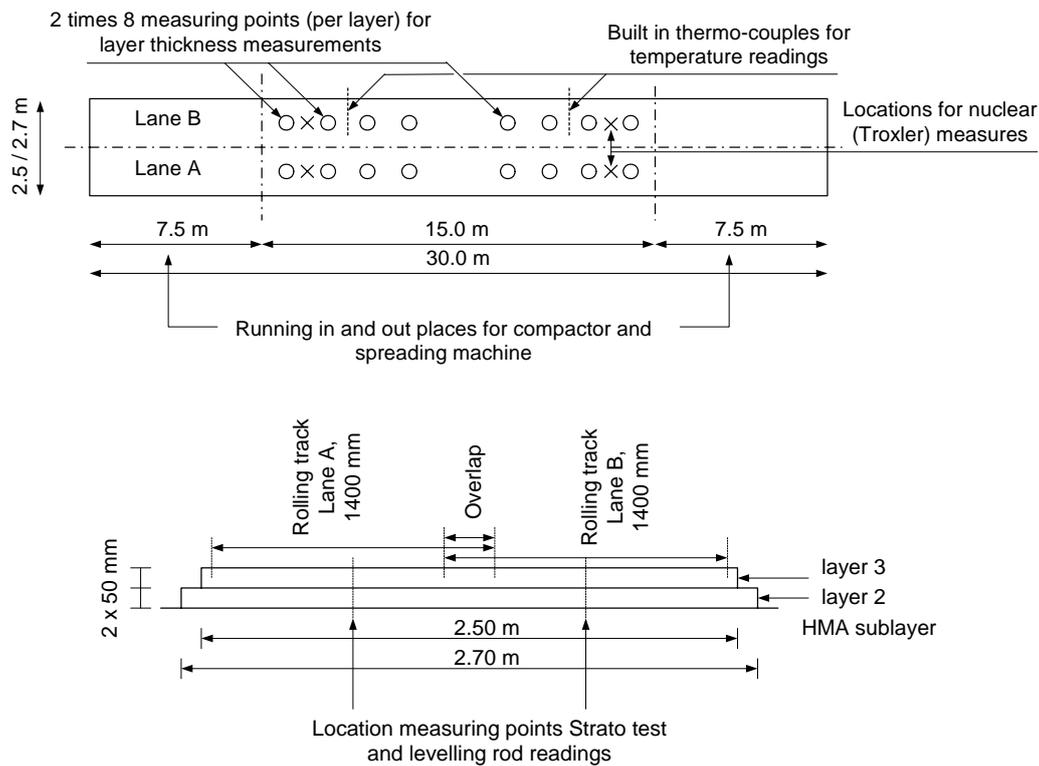


Figure 3: The cross section and a plan of the realised compaction test section.

2.3. Conditions during compaction and preliminary estimations

To estimate the number of roller passes required for achieving adequate compaction a literature study was made. It can be deduced from Nijboer (1948) in combination with SCW (1978) that a mixture as the DAC 0/16 can be compacted to the minimum requirement of 98% Marshall density with approximately 16 passes of the HAMM DV 6 when the average material temperature was around 110°C during the compaction. The amount of roller passes of 8 and 16 (respectively lanes A and B) seems for this target a reasonable starting point.

Other investigations in cooling processes of HMA during rolling like Vizi (1981) and Bossemeyer (1966), indicate that cooling of a HMA at an initial temperature of 160°C to 70°C takes about 30 minutes when ambient temperature was around 10°C and wind speed was between 2 to 4 m/sec. This implies that when 16 roller passes should be applied (A lanes), approximately 2 minutes were available for a particular roller pass including all the accompanying measurements. This applies severe constraints to the execution of the measurement programme including; the layer thickness (2x), time, temperature and specific density.

2.4. Instruments

The layer thickness measurements were carried out with both a level and rod and with the Strato tester. The Strato tester is a radar type of equipment and that uses reflection of the radar waves by an aluminium object embedded in the layer. Therefore the Strato tester requires accurate positioning. The Strato Test equipment allows very rapid thickness measurements. After the equipment was calibrated to the asphalt temperature it takes less than 5 seconds to obtain a reading. The thickness was measured after every roller pass at positions marked in advance as shown in Figure 4.



Figure 4: All measurements (temperature, level and rod, Strato test and Troxler) in progress.

Level and rod readings were rather time consuming and because measurements had to be achieved within narrow time constraints it could happen that not all points were measured after every pass. The density of the material was measured at two positions using nuclear (Troxler) equipment (Figure 3). After compaction of the test section was completed, cores were drilled at all the 16 measuring points. From these cores, the layer thickness and specific density could be obtained. The temperature of the HMA under construction was measured at three depths in the layer at two locations (see Figure 5). For each reading, the time at which the temperature readings were taken was noted. Thermo couples buried in the layer were used to record temperature, while synchronised chronographs were used to measure the time. Temperature-time relation, could be plotted from the measurement results.

3. ANALYSIS OF THE TEST SECTION RESULTS

The most important aspect of this research concerns the change of layer thickness (or specific density increase) of the HMA in relation to a particular roller pass and the temperature of the material at that specific moment. Analysis of the results will be discussed in the following order;

- Roller passes versus time
- Temperature versus time
- Layer thickness versus roller passes

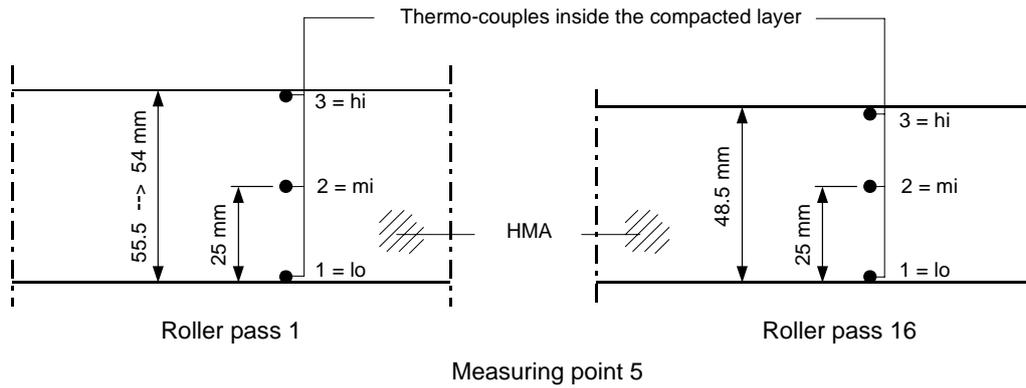


Figure 5: Positioning of the thermocouples in the layer under construction.

3.1. Analysis of the applied roller passes in time.

Based on the ideas earlier discussed in this paper one part of the compacted layers (subsequently called A lanes) was compacted with 16 roller passes whereas the B lanes were compacted with 8 passes. For both lanes the number of roller passes were equally distributed over the time available for compaction. This implies that the respective roller passes on the B lanes were always applied later (and at a lower temperature) than the same numbered pass on the A lanes.

During construction of the test section, the spreading of the new asphalt layer and roller passes applied were timed by using a chronograph. Both time and temperature readings were taken simultaneously. Determination of the time a specific roller passed made it possible to calculate the material temperature during the specific roller passes on the newly laid HMA. Separate functions were estimated for the two lanes. The expected slope of the B line should be twice the slope of the A line because on the first one half the number roller passes were applied in approximately the same time span. The distribution of the applied roller passes over the time available for compaction and the model that represents this are illustrated in Figure 6.

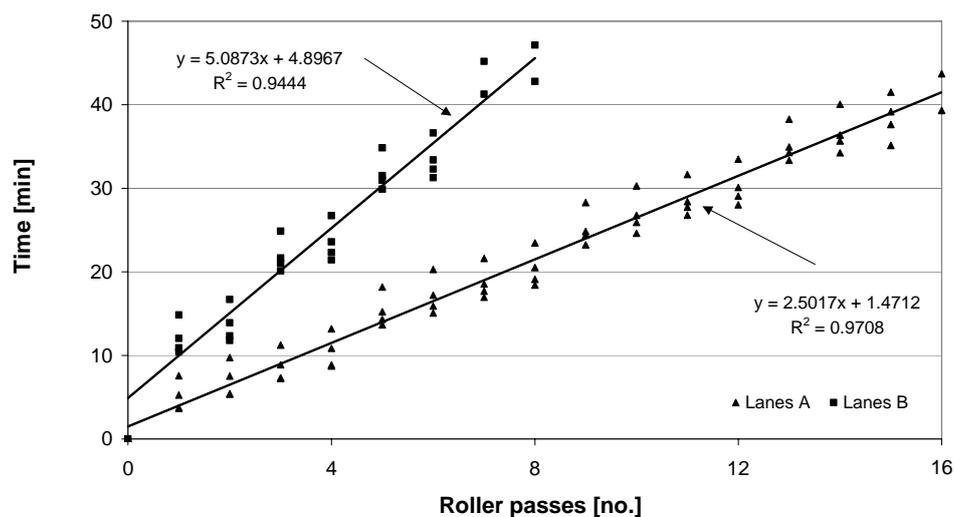


Figure 6: The distribution of the roller passes over time after paving the HMA lanes A & B.

3.2. Analysis of the HMA material temperature

During compaction time and temperature readings were taken (Table 2). Registration of the compaction and cooling process in time made it possible to calculate the material temperatures at each specific roller pass. The relation used for describing the cooling behaviour is log-linear; the logarithm of temperature versus the time in minutes. A generic relation was developed that models the cooling behaviour at three different depths in the layer; at the positions low (“Lo”), middle (“Mi”) and high (“Hi”).

Similar procedures could be used to achieve the generic temperature relations at the positions “Hi” and “Mi” for both layers 2 and 3. However, this was not the case for position “Lo”. This was probably because both HMA layers were constructed in a limited time on top of each other (layer 3 on top of layer 2). Layer 2 was constructed on a sub-layer at ambient temperature whereas layer three was constructed on a warm layer (layer 2). Due to this construction process the material temperature trajectories of the layers at position “Lo” were different.

Table 2: Measured temperatures at position “Mi” at comparable rolling passes, lanes A and B

Temperatures °C during roller passes			
Roller pass no.	Lane A	Lane B	Difference
2	122	103	19
4	110	84	26
6	100	69	31
8	91	58	33
10	82	-	-
12	75	-	-
14	68	-	-
16	62	-	-

Based on this information the estimated absolute temperature trajectory can be calculated by using the following relation;

$$T_{HMA_c} = \delta T_c + T_{air} = \delta T_{ini} \times 10^{(S \times t + I)} + T_{air}$$

- where;
- T_{HMA_c} = The current HMA material temperature [°C]
 - δT_c = current difference between material and air temperature [°C]
 - T_{air} = environmental air temperature during construction [°C]
 - T_{ini} = initial material temperature (i.e. during spreading the HMA) [°C]
 - S = slope of the model
 - I = intercept of the estimated model
 - t = time in minutes after spreading of the HMA

Using the equation the HMA temperature can be estimated. In Figure 7 the modelled and measured temperature data are plotted against time after paving, for layer 2 thermo couple 1.

3.3. Analysis of compaction progress

During construction of the experimental test section the layer thickness was monitored by means of Level and rod and Strato test measurements. Additional to this the progress in compaction was monitored with nuclear density readings. The density of the HMA during compaction can be linked to the layer thickness and vice versa if for a specific point in time both variables are known (e.g. obtained from measurements on cores in the final stage).

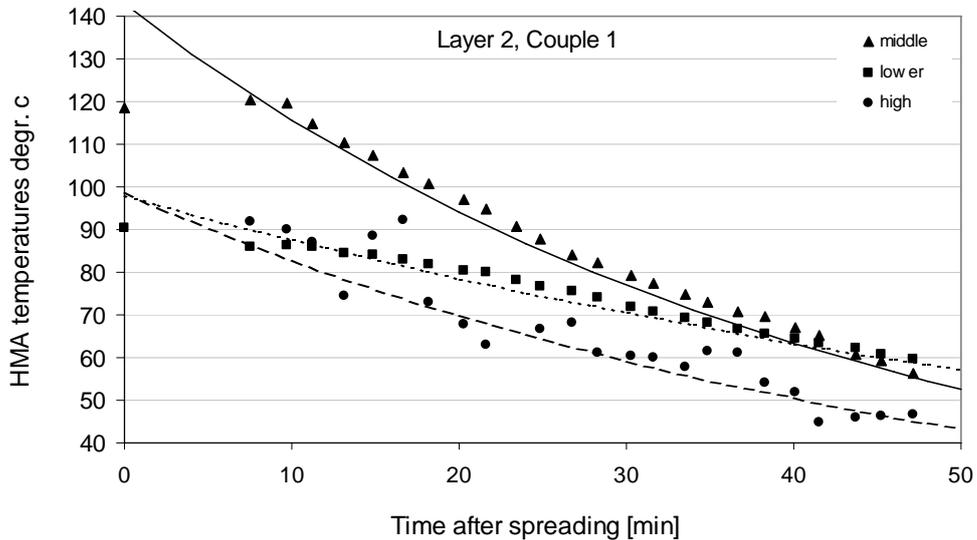


Figure 7: The calculated and measured HMA temperatures based on the measurements during rolling layer 2, thermo-couple 1, all positions.

In Figure 8 all layer thickness readings are depicted against the number of roller passes. The layer thickness data at a fixed stage during the compaction was corrected to the average thickness for all measuring points and then depicted against the number (log) of roller passes. The data suggest that there is a logarithmic relation between the number of roller passes and trajectory of layer thickness. In fact this corresponds with Kezdi (1969) and Renken (1980).

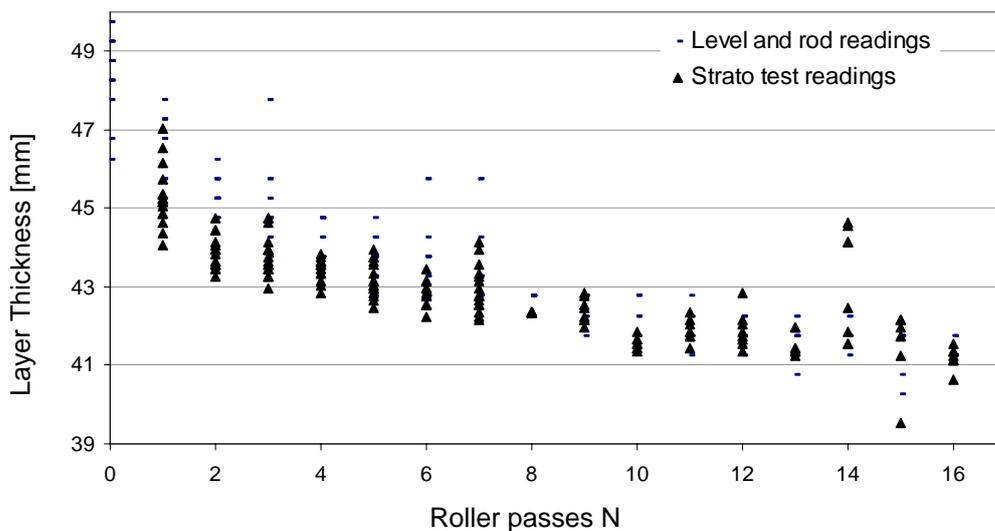


Figure 8: Measured Layer thickness (corrected) against roller passes, Strato test and Level and rod readings.

This trajectory of the layer thickness during compaction motivated to transform the data to the following relation;

$$LT_N = LT_\infty * (1.0 + \gamma * 10^{(-\alpha * N)})$$

in which;

$$\gamma = \frac{LT_0 - LT_\infty}{LT_\infty}$$

and;

LT_N = layer thickness after a given number of roller passes

LT_∞ = theoretical Layer thickness after an infinite number of roller passes

LT_0 = layer thickness before compaction starts (thickness after spreading)

N = applied number of roller passes

α = factor that represents speed of compaction progression

The variable γ represents the pre-compaction state related to the ultimate compaction state possible. If it is assumed that pre-compaction level over the whole layer was homogeneously this variable can be estimated as a fixed parameter for the process (all measuring points). The above equation was used for establishing the layer thickness trajectory separately for;

- Different lanes (for temperature reasons)
- Different measuring methods level and rod and Strato test

Because the layer thickness was monitored using two different types of equipment it was easy to consider the differences measured by the two sources of information. The analysis showed that, although very classic, the level and rod measures were more accurate and reliable. Therefore in the rest of this paper only information based on this source will be used.

3.4. Effects of material temperature on compaction progress

To investigate if there really exists a difference in compaction progression when the HMA is at different temperature, the compaction progress of the different test lanes A and B were compared to each other. This comparison was possible given the way how the programme was set up.

For example, roller pass 2 on the B section was applied 15 minutes after spreading when the mean temperature was 103°C. On lane A roller pass 2 was applied about 6.5 minutes after paving at a temperature of 122°C, see Table 3.

Table 3: The results of the analysis of the slopes of the decrease of layer thickness of layers 2 and 3, lanes A (16 passes) and B (8 passes).

Analysis of α & γ	Lanes A	Lanes B	Variance
α	-0.0945	-0.0985	0.004
St. dev. (α)	0.06	0.05	
γ	0.1497	0.1497	

The effect of temperature on compaction progress against the number of roller passes was estimated for all measuring points. The variables, α and γ , which represent the compaction progress were calculated separately for the A and B lanes. The obtained difference in α 's for both lanes is so small, see Table 3, that considering the standard deviation, statistically they act as two samples from the same population. This implies that during compaction of our test section, on both involved lanes compaction progress was approximately equal (in fact the α value for the B lanes was even a bit higher), although the temperatures between both lanes differed considerable (19°C for roller pass 2 and 33°C for roller pass 8). These results do not

underscore opinions that live in road building practice; here it is meant that high material temperatures are crucial for good compaction progression.

Because based on the data the data it cannot be expected that there was a difference in compaction progress at different temperatures, the same formula parameters were used to predict the layer thickness trajectory for all the measuring points. This implies that the formula does not contain a temperature parameter nor a parameter that reflects the involved section. The formula is already expressed on page 9.

In addition to monitor compaction progress during construction, the densities of the HMA were also measured by using two nuclear Troxler gauges. The compaction progress obtained by the Troxler readings was different from the one obtained by level and rod measures. Mainly during the first part of compaction, approximately nine roller passes (i.e. 2373 kg/m³ or 98 % of Marshall density) Troxler readings overestimate the achieved material density related to level and rod measures. After that stage both techniques do obtain similar results. The results are depicted in Figure 9.

The Troxler density readings obtained after the last roller pass were compared to densities obtained on cores, which were drilled from the pavement after compaction was completed. The results show that one involved Troxler device underestimates the specific density with approximately 13 kg/m³, whereas the other Troxler overestimates the specific density with about 62 kg/m³. Perhaps further work should be done into accuracy of the Troxler readings when used in un-compacted layers.

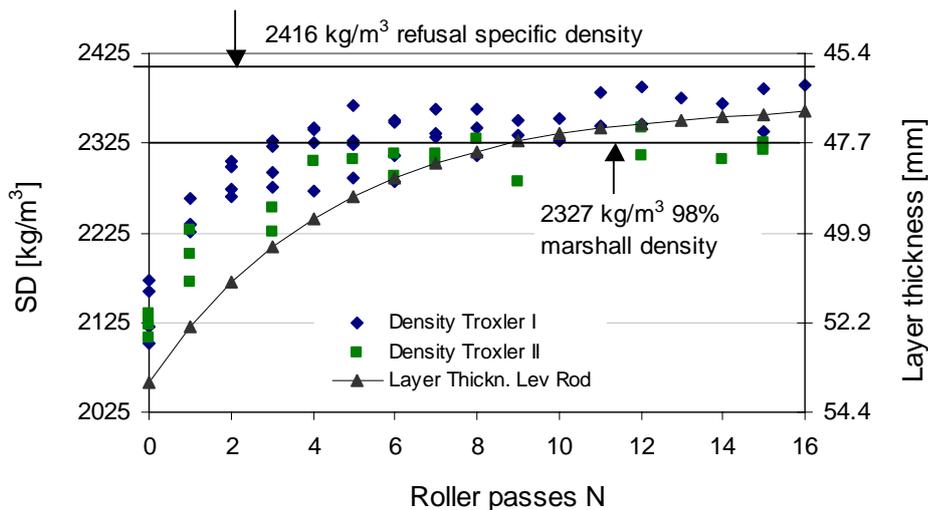


Figure 9: The estimated layer thickness trajectory compared to layer thickness values deduced from nuclear density measures.

CONCLUSIONS AND RECOMMENDATIONS

For compacting an initially 54 mm thick HMA layer (DAC 0/16), pre-compacted to 86% of Marshall density with a 7.9 tons static steel roller, under described meteorological conditions, the following conclusions could be drawn;

For both layers 2 and 3 in the construction similar procedures could be used to achieve generic temperature relations at the positions in top and middle of the layers, but not for the position at the bottom of the layers. This is due to the fact that layer two was constructed on a sub-layer at ambient temperature, while layer three was constructed on a warm layer.

Two involved lanes were compacted at different temperatures and different numbers of roller passes. Although the temperature difference between the two involved lanes increased to 33°C at roller pass no. 8 no significant difference was found in compaction progress. Compaction was completed when the material cooled to about 60°C measured in the middle of the layer.

The results show that 98% of Marshall density was achieved after 9 roller passes, see Figure 9, measured on lanes A. On lane B only 18 roller passes were applied. Because compaction progress trajectory measured until 8 roller passes was completely identical for the lanes A and B, it was expected that on B lanes also after the 9th roller pass 98% of Marshall density would be achieved.

All obtained readings in relation to compaction were compared to each other. It could be seen that the accuracy of Nuclear and Strato test equipment was sufficient at the tail of the compaction process (globally after 8 to 10 passes were applied). At the beginning the Troxler's overestimated the density (Figure 8) whereas the Strato tester overestimated the layer thickness, and thus underestimated the density (Figure 9).

It is recommended to do more detailed research after the accuracy and reliability of gauges that make use of radar waves especially at the beginning of the compaction where density is low and materials are hot.

Specific density during rolling was monitored by using two Troxler's. The readings taken after compaction completed were compared to densities measured on the drilled cores. The results show that there was a structural deviation between both involved gauges. During construction of this test section only one (type of) roller was used to a layer of one material mixture with a single layer thickness. It is recognised that this limits the scope of the research. It is recommended to do more tests with different (types of) rollers (static, dynamic, weights), different mixtures, different layer thickness's etc.

It is also recommended to simulate the compaction progress at the two rolling temperatures by e.g. the use of an FEM programme to see if similar conclusions can be drawn.

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