Asphalt Pavements – Kim (Ed)

Including asphalt cooling and rolling regimes in laboratory compaction procedures

Frank R. Bijleveld & André G. Dorée
Department of Construction Management and Engineering, University of Twente, Enschede, The Netherlands

ABSTRACT: Given the various changes occurring in the asphalt construction industry, improved process and quality control is becoming essential. The significance of appropriate rolling and compaction for the quality of asphalt is widely acknowledged and vital for improved process control. But what constitutes appropriate rolling and what are appropriate instructions for operators? Existing laboratory procedures generate a single compaction temperature based on binder viscosity. However, in practice, roller operators choose various windows in terms of both time and temperature for compaction activities. This makes it difficult to design the compaction process and give proper instructions to operators.

This research project has aimed to (1) develop laboratory compaction procedures that take account of asphalt cooling during compaction and (2) determine the effects of different compaction strategies on the asphalt quality. Field compaction processes for two mixtures, an AC 16 base/bind and SMA 11 surf, were simulated in the laboratory using different temperature windows and applying different rolling regimes using a slab compactor and a 2.5 ton roller to produce 500 mm square slabs. The resultant densities and Indirect Tensile Strengths (dry and retained) were assessed based on 16 cores drilled from each slab.

The experimental results show that it can be important to design rolling strategies within clearly defined temperature windows. If an SMA 11 surf is compacted outside the optimal temperature window, or using a sub-optimal rolling strategy, the density may drop by 30 kg/m^3 and the Indirect Tensile Strength fall by up to 10%. Such experimental results are vital if one is to design appropriate rolling regimes and give appropriate instructions to roller operators. Also, the results can help to close the gap between field processes and laboratory compaction techniques. Overall, the results reflect a valuable step in the quest toward improved process and quality control.

Keywords: Asphalt temperature, cooling, compaction, density, Indirect Tensile Strength

1 INTRODUCTION

The final stage of the asphalt road construction process remains a grey area when it comes to quality control. Although substantial research effort is put into creating a mix with the desired characteristics, the actual compaction sequence, once this is delivered to a site, primarily depends on the experience and gut feelings of the roller operators. This unknown element in quality control is of increasing concern to contractors. The search is on for properly validated compaction procedures because significant changes are occurring in the asphalt construction industry that result in new roles for agencies (clients) and contractors. In particular, agencies are shifting toward service-level agreements with lengthy guarantee periods. With these new roles and contracts, contractors are directly confronted with any quality shortcomings that appear during the guarantee period. As such, it is important for contractors to professionalize their operations and improve process and quality control during construction. The current asphalt construction process is mainly based on experience and craftsmanship, and is still mostly carried out without the use of high-tech instruments to monitor key process parameters, and little research effort has been put into the systematic mapping and analysis of construction processes [1]. Therefore, contractors have little knowledge of what actually transpired during construction and how the operations were carried out. It is therefore near impossible to relate the operations to quality parameters, to identify poor and good practices, and thus also to improve process control.

In the current technological age, various technologies are being developed to make construction processes explicit in real-time by both geodetic companies (Trimble, Topcon) and machine manufacturers (Bomag, Wirtgen, Ammann, Dynapac, Caterpiller). Using modern technologies, it becomes possible to make the construction processes explicit and systematically monitor, map, and analyze on-site processes. Several studies have demonstrated, using these technologies, that there is significant variability in both construction processes and key parameters [1–4]. To reduce this variability, it is essential to change from the current experience-based working methods toward a more method-based working. To enhance this change, it is vital to design and specify the optimum construction process before actual construction. However, it is difficult to relate the various construction processes to quality parameters in field projects given the many changing variables. Ideally, one would like to design the construction process in advance within the laboratory. However, procedures to design on-site construction processes within the laboratory are lacking and thus there remains a lack of appropriate instructions for operators. If the process could be designed in advance in the laboratory, better instructions could be provided for on-site operators.

This paper focuses on the compaction process in the laboratory (a process which on-site uses rollers). The existing laboratory compaction procedures mainly generate a single optimum compaction temperature based on binder viscosity. However, in practice, roller operators use a range of time and temperature windows for compaction (observed using GPS tracking and on-site measurements). This paper proposes a procedure to accommodate asphalt cooling and compaction rolling regimes in laboratory compaction procedures. The paper starts with a literature review of research addressing asphalt compaction, followed by the objectives and approach followed in this research. Next, the compaction procedures and materials used will be described, followed by the experimental results. The paper concludes by addressing the implications of the findings for the asphalt industry and considering opportunities for future research.

2 LITERATURE ASPHALT COMPACTION

2.1 *Asphalt compaction*

An extensive literature review by Miller [1] concludes that the majority of the literature deals with the characteristics of asphalt from the perspective of a construction material and that only about 5% of the asphalt-related journals deal with asphalt laying and compaction operations. Further, in this small research area, the studies have been conducted in separate niche areas such as 'temperature variability', 'temperature segregation', and 'compaction problems'. Nevertheless, this literature [1,5,6] has identified two important facets within the construction process that are important for the final quality of the asphalt pavement: (1) compaction operations; and (2) the asphalt temperature during these compaction operations.

First, there are the compaction operations: inadequate compaction in vital areas of the road section can lead to premature failure. Roller operators have a limited window of opportunity to carry out their operations if they are to reach a certain quality level [7–12]. They have to take into account a number of factors including the temperature of the existing surface, the initial material temperature, the thickness of the layer, and the weather conditions. Further, the operators have to perform their tasks under frequently changing site conditions involving wind, rain, and layer thickness [1,7,8]. This all contributes to compaction being a complex task.

The second facet is the temperature of the asphalt mixture during the paving and compaction phase. In the asphalt paving industry, both researchers and practitioners recognize that the temperature of the asphalt mixture during compaction is an important determinant of the final quality of the pavement [1,7,12–17]. Some authors suggest that compaction should be completed in a specific temperature range such as between 90 °C and 100 °C [13] or have specified either maximum temperatures of about 130 °C [18] or minimum temperatures between 70 and 80 °C [19, 20]. If the material temperature is too low during compaction, the bitumen can no longer lubricate the mixture resulting in an open surface. If the temperature is too high, the binder is too fluid and the resulting aggregate structure is weak as the roller loads will simply displace or "shove" the material rather than compact it, cracks may originate behind the rollers, and the rollers sink into the mixture. Kari [10] describes these minimum and maximum temperatures as understressed and overstressed situations.

Traditionally, the optimal compaction temperature has been determined by plotting log-viscosity vs. log-temperature, and the ideal compaction temperature coincided with a bitumen viscosity of 1.7 poise [21]. Subsequently, Jordan and Thomas [22] and Luoma et al. [23] developed tools to predict a temperature window, and the starting and ending temperatures at which to compact. Later, Chadbourn et al. [7] and Timm et al. [12] developed Windows-based computer programs (PaveCool, Calcool, and Multicool) that produced solutions that predicted the pavement cooling phenomenon and suggested starting and stopping times for compaction. The main problem with these methods is that they are based on viscosity and density rather than final quality characteristics such as resistance against fatigue, rutting, and cracking. Decker [24] argues that determining the compaction temperature through viscosity-temperature plots is no longer appropriate with more viscous bitumens since these can have a higher compaction temperature leaving insufficient time to compact the mixture. Similarly, Bahia et al. [25] showed that these traditional approaches indicated unreasonably high temperatures for modified asphalts.

In conclusion, the compaction process and the temperature during this process are key determinants of the final quality of the pavement. However, how the density and mechanical properties of the pavement are influenced by the various operational compaction strategies remains unclear.

2.2 *Simulation of field compaction in the laboratory*

Several studies have shown that conventional laboratory compactors, such as Marshall compactors, vibratory compactors, and gyratory (kneading) compactors, do not truly simulate the compaction in the field. In the last decade, a new type of compactor has entered the laboratory asphalt compaction market—the rolling compactor (EN 12697-33)—that produces relatively large slabs. The principle of these compactors is a segmented roller that moves back and forth across the mixture in a mold to produce relatively large slabs, often 500 mm by 500 mm.

From various studies, it has become clear that rolling compaction is closest to field compaction [26–30]. Also, the instrument can be pre-heated and can produce several test samples at the same time, and this diminishes variability between subsequent tests. The University of Wuppertal has conducted research so as to be better able to simulate, in the laboratory, field compaction and more accurately simulate pre-compaction [28]. These new laboratory compactors are available on the international market. Companies in Europe, including BPS Wennigsen and Infratest Testing Systems in Germany (who have sold 66 machines worldwide since 2006) have developed several compactors as has IPC Global based in Australia. However, less research effort has been put into determining relationships from an operational (process) perspective related to the final mechanical properties of the asphalt mixture. As a result of these studies and developments, we believe that rolling compaction has now reached a stage where it can play an important role in simulating the field compaction process, and with that in the design of improved compaction procedures. The next section discusses the objectives of this research and the approach followed.

3 OBJECTIVES AND APPROACH

The objectives of this research were: (1) to develop laboratory-scale compaction procedures that include asphalt cooling; (2) to develop laboratory procedures to imitate actual rolling regimes with various rollers; and (3) to compare the compaction procedures used in various laboratories using different compaction methods. Overall, the aim was to improve understanding of operational strategies and narrow the gap between field compaction and compaction in the laboratory. The objective of this paper is to demonstrate the merits of the developed compaction procedures and the range of experimental results when the compaction procedures were varied.

To achieve the objectives, three experiments were designed and conducted. In these experiments, some elements of the compaction process were varied and quality parameters were determined. More specifically, the temperature window and the roller types used for compaction were varied (the independent variables) and the quality of the finished product was determined in terms of density and Indirect Tensile Strength (ITS) (the dependent variables).

The 'temperature window' variable warrants further explanation. From the literature review, it is clear that the traditional approach to specifying the compaction temperature from laboratory tests results in a single compaction temperature based on viscosity whereas, during field compaction, subsequent roller passes are made while the asphalt mixture cools, resulting in a temperature window. Timm et al. [12] put forward the idea that there is an ideal window of temperatures in which to compact the asphalt mixture and, if this is met, then it is highly likely that the desired mechanical characteristics will be achieved. Depending on the cooling rate of the asphalt mixture, this also means that there is an optimal time window in which to compact. If the asphalt mixture is compacted outside these windows, the asphalt mixture will be understressed (if the mixture is compacted at too low temperatures) or overstressed (if the temperatures are too high). Figure 1, which shows schematically the temperature of the mixture as a function of time, illustrates these conditions.

4 MATERIALS AND COMPACTION PROCEDURES

The experiments were conducted using two asphalt mixtures, namely an AC16 base/bind and an SMA 11 surf. These mixtures were chosen since the AC 16 base/bind is a frequently used asphalt mixture under less than ideal circumstances in the Netherlands and the SMA 11 surf is known to be a critical mixture in terms of compaction. Both mixtures were made without incorporating Recycled Asphalt (RAP) in order to increase the homogeneity of the mixtures. All the materials were ordered as a single batch to decrease the risk of excessive variability in the raw materials. The compositions of the two asphalt mixtures are shown in Table 1. These mixtures were then compacted using two different compaction methods, namely a Slab Compactor (SC) and small 2.5 ton Roller Compactor (RC) to create 500 mm squared slabs—shown in Figure 2.

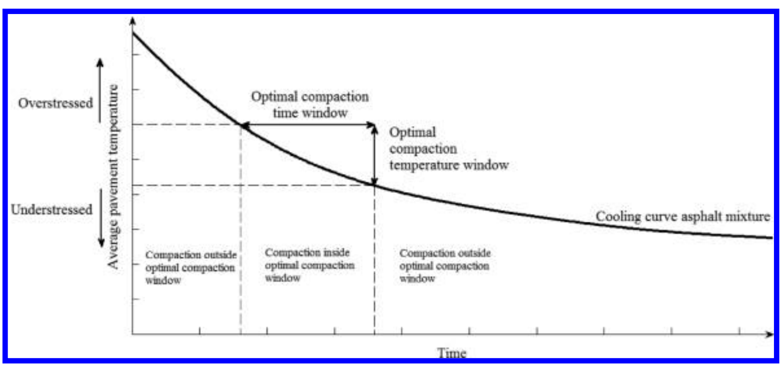


Figure 1. Compaction window (based on Timm et al. [12]).

Table 1. Composition asphalt mixtures.

Material	AC 16 base/bind	SMA 11 surf
Bestone 4/8	–	30.9%
Bestone 8/11	–	47.3%
Granite 2/8	22.7%	–
Granite 8/16	35.0%	–
Sand	35.8%	12.0%
Wigras 40 K (filler)	6.5%	9.8%
Bitumen 40/60	4.5%	–
Bitumen 70/100	–	7.0%

Figure 2. Slab compactor (left) and 2.5 ton roller (right).

Three experiments were designed and conducted: (1) varying the temperature window for the AC 16 base/bind mixture using both compaction methods, (2) varying the temperature window for the SMA 11 surf mixture using both compaction methods, and (3) varying the rolling regime for the SMA 11 surf mixture using only the slab compactor. The specified compaction procedures are shown in Table 2. In total, 47 slabs were produced in four laboratories from which 752 cores were extracted and analyzed.

The steps (i.e. the procedure) conducted in the experiments were as follows:

1. Mixing the raw materials. This involved heating the bitumen and aggregate to 170 °C. First, the aggregate, sand and filler were put in the mixer, these were mixed for 15 seconds, then the bitumen was added and mixed for 3 minutes.
2. Compacting the asphalt mixture using the slab compactor or the 2.5 ton roller. First, the asphalt mixture was pre-compacted to 90% of the target density (simulating screed compaction). Then the 4–5 rolling phases shown in Table 2 were simulated (also based on procedures from Mollenhauer [31]).
   a. To ensure the roller passes were carried out at the intended temperatures, thermocouples were placed in the asphalt mixture at the bottom and middle of the height through the slab. In practice, there was little difference between these two temperatures so the slabs can be considered homogenous in terms of temperature.
   b. The loads applied by the slab compactor were calculated based on the Dutch roller factor, which is calculated by the load of the roller divided by the product of the width and the square of the diameter of the roller. A force of 14 kN was used to simulate a tandem roller, and a force of 25 kN to simulate a three-drum roller.
3. Drilling and removing cores from the slab. Sixteen cores with a diameter 100 mm were extracted from each slab according to a standard drilling scheme.
4. Determining the dimensions and densities of the drilled cores. The dimensions of the cores was measured four times using a digital rod and the density was determined by a procedure based on Archimedes' Law.

Table 2. Design of the compaction procedures.

Experiment 1: AC 16 base/bind		
Procedure 1: 10 slabs	Procedure 2: 3 slabs	Procedure 3: 2 slabs
5 tandem passes at 150 °C 5 tandem passes at 115 °C 5 tandem passes at 90 °C 5 tandem passes at 70 °C	5 tandem passes at 120 °C 5 tandem passes at 100 °C 5 tandem passes at 80 °C 5 tandem passes at 60 °C	5 tandem passes at 120 °C 5 tandem passes at 80 °C 5 tandem passes at 60 °C 5 tandem passes at 40 °C
Experiment 2: SMA 11 surf		
Procedure 1: 12 slabs	Procedure 2: 12 slabs	
5 tandem passes at 150 °C 5 tandem passes at 115 °C 5 tandem passes at 90 °C 5 tandem passes at 70 °C 5 tandem passes at 50 °C	5 tandem passes at 120 °C 5 tandem passes at 100 °C 5 tandem passes at 80 °C 5 tandem passes at 60 °C 5 tandem passes at 40 °C	
Experiment 3: SMA 11 surf		
Procedure 1: 3 slabs	Procedure 2: 3 slabs	Procedure 3: 2 slabs
5 three-drum passes at 150 °C 5 three-drum passes at 115 °C 5 three-drum passes at 90 °C 5 tandem passes at 70 °C 5 tandem passes at 50 °C	5 tandem passes at 150 °C 5 tandem passes at 115 °C 5 tandem passes at 90 °C 5 three-drum passes at 70 °C 5 three-drum passes at 50 °C	5 tandem passes at 150 °C 5 tandem passes at 115 °C 5 tandem passes at 90 °C 5 tandem passes at 70 °C 5 tandem passes at 50 °C

5. Polishing the cores: The AC16 base/bind slabs were compacted to a thickness of 80 mm and polished to a depth of 60 mm for testing. The SMA 11 surf slabs were compacted to 60 mm and polished to 50 mm for testing.
6. Determining the dimensions and densities of the polished cores. As in Step 4, the dimensions were measured four times using a digital rod and the density was determined using Archimedes' Law.
7. Conditioning of the polished cores: Eight cores were conditioned in air at 15 °C for 72 hours (further called dry cores) and eight cores were conditioned in a water bath at 5 °C for 72 hours (further called retained cores).
8. Conducting ITS tests: ITS tests were conducted according to EN-12697–23. The ITS tests determine the peak load (P_{max}), the Indirect Tensile Strength (ITS), the work of fracture (W_f), and the fracture energy (G_f). The fracture energy was calculated according to the RILEM TC 50-FMC specification (1985). The work of fracture (W_f) was computed as the area under the load(P)—displacement(u) curve, and the fracture energy (G_f) was calculated by dividing the work of fracture by the ligament area (the product of the diameter (D) and the height (H) of the specimen).

5 EXPERIMENTAL RESULTS

Three experiments were conducted in four different laboratories. These laboratories are here numbered 1 to 4, and in 1 and 2 the mixtures were compacted using a Slab Compactor (SC) and in 3 and 4 the mixtures were compacted using a 2.5 ton Roller Compactor (RC). From each compacted slab, 16 cores were extracted and analyzed. The following aspects were assessed in detail: (1) layer thickness progression during compaction; (2) density before and after polishing; and (3) indirect tensile strength.

5.1 *Experiment 1: Varying temperature window—AC 16 base/bind*

The progression in the layer thickness during compaction is automatically determined when using a slab compactor and determined using a theodolite in the laboratories using a 2.5 ton roller. The progression in layer thickness using the slab compactors (laboratories 1 and 2) showed a consistent trend as shown in Figure 3: During pre-compaction, the layer thickness decreased by around 3–4 mm. In the first three roller phases, the layer thickness decreased by 0.1–0.6 mm in each phase. Following this, in the final phase, the layer thickness increased slightly (0.2–0.3 mm). These results are similar to the results of Faheem et al. [32] who also found that density does not always increase as the temperature falls, as we saw in the last compaction phase in our testing. In contrast, the changes in the layer thickness using the 2.5 ton roller (laboratories 3 and 4) were much more variable and no trend could be discerned.

Next, the densities of the extracted asphalt cores were determined. With this mixture, no significant differences in density were observed for a given procedure undertaken in different temperature windows. However, differences in density were observed between the two compaction methods and between the laboratories. The average slab density compacted with the slab compactors was 2296 kg/m^3, whereas the average density of slabs compacted with the 2.5 ton roller was 2339 kg/m^3. Also, the average density of slabs compacted with the same roller procedure was 2301 kg/m^3 in one laboratory and 2371 kg/m^3 in the other. The density variability within a slab was also analyzed and the variation within a slab was of a similar order. The average difference between the minimum and maximum densities within a slab was 53 kg/m^3.

Finally, the results of the ITS tests, presented as fracture energy (G_f) values in Figure 4, were considered. We concluded that there were large differences between ITS results for slabs compacted using the same procedure—both from slab to slab and from lab to lab. For the

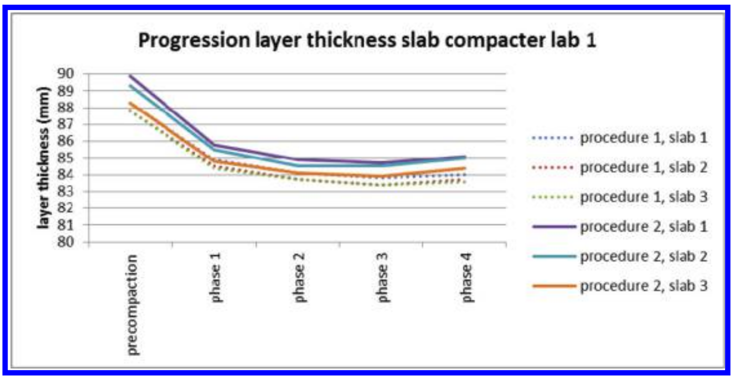


Figure 3. Progress in the layer thickness using the slab compactor.

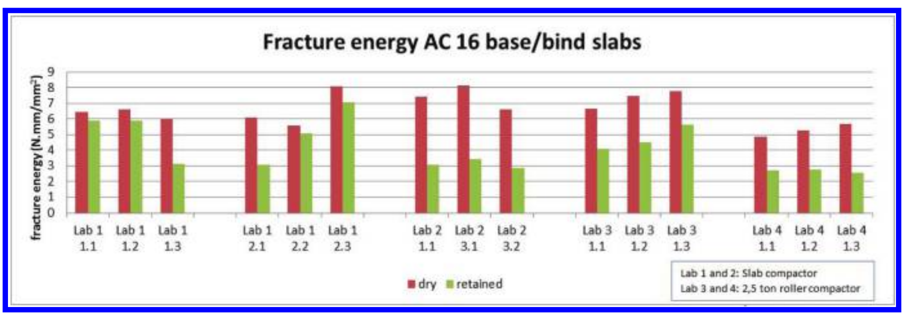


Figure 4. Average fracture energy values AC 16 base/bind slabs.
*The coding indicates the procedure (1st number) and the slab number (2nd number).

dry samples, G_f values ranged from 4.9 to 8.2 Nmm/mm^2. Given this high variability from one slab to another, it was not possible to determine a relationship between the different compaction procedures. Further, it is apparent that the retained ITS values of the slabs compacted in laboratories 2 (SC) and 4 (RC) are relatively low compared to those in the other two laboratories (by 1.97 Nmm/mm^2 on average). As a consequence, the ratio between the dry and retained values (ITSR) are relatively low in laboratories 1 (SC) and 3 (RC), and overall show a wide range (41–91%).

5.2 *Experiment 2: Varying temperature window SMA 11*

SMA 11 surf slabs were compacted in two different temperature windows, namely at 150-115-90-70-50 °C (Procedure 1), and at 120-100-80-60-40 °C (Procedure 2). Five roller passes with a tandem roller (Hamm DV70) were carried out in each of the five rolling phases.

Again, the progression in layer thickness during compaction was more consistent using the slab compactor than the 2.5 ton roller. Using the slab compactor it was possible to compact slabs with a maximum difference in layer thickness of 2.5 mm (59,7–62,2 mm). Using the 2.5 ton roller, the differences in thickness were much more variable (58,9–65,3 mm).

From an analysis of the progression in layer thickness, it seems that Procedure 2 was less successful in achieving the desired layer thickness than Procedure 1. This is also reflected in the final densities of the extracted cores. Although all the cores show a compaction degree of 100 to 102%, the densities of the cores compacted using Procedure 2 are approximately 30 kg/m^3 lower than those produced using Procedure 1. As with the AC16 base/bind mixture, the variability in density within a slab was high. Differences between the minimum and maximum densities in a slab were as high as 80 kg/m^3. However, the cores extracted from the central area of the slabs were much more consistent with the maximum difference between the minimum and maximum densities within a slab being 25 kg/m^3.

ITS tests were performed on the extracted and polished cores. Even when the largest differences in density were discounted (by selecting the middle cores of the slabs), there still seems to be a difference in ITS values between the cores compacted using the two procedures. The ITS values from the cores compacted according to Procedure 1 vary from 0.91–1.09 MPa, and using Procedure 2 from 1.01–1.20 MPa. The average ITS of the cores compacted using Procedure 2 was 0.11 MPa (≈10%) higher than the ITS of those compacted using Procedure 1. We then looked for a relationship between the density and the ITS of the cores. No relationship was found between the ITS and the density, for the obtained density range (2330 to 2370 kg/m^3).

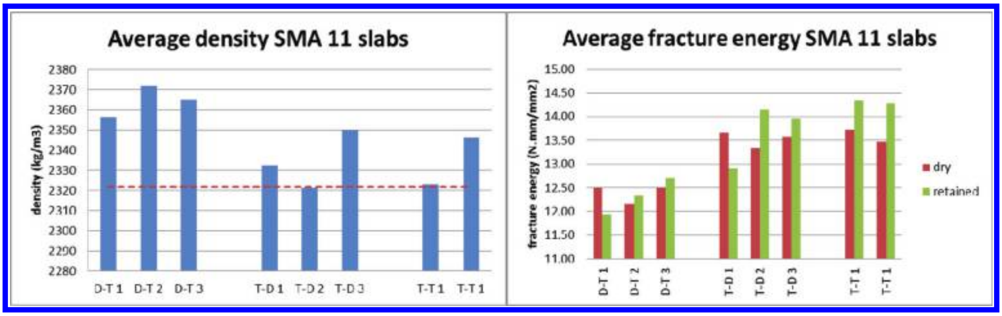
5.3 *Experiment 3: Varying roller regime SMA 11*

In Experiment 3, SMA 11 surf slabs were compacted following three different roller regimes, namely using a three-drum roller and then a tandem roller (further called D-T), using a tandem roller and then a three-drum roller (further called T-D), and using a tandem roller, followed by a second tandem roller (further called T-T). In all cases, compaction took place in five phases at temperatures of 150–115–90–70–50 °C with five roller passes in each phase.

The successive changes in layer thickness show that the D-T rolling regime results in a much faster reduction in slab thickness than in the slabs compacted using the T-D and the T-T rolling regimes.

Following the procedure, next cores were extracted and analyzed. All the slabs achieved the target density or higher densities. However, the cores compacted using the D-T rolling regime were denser than both the target density and the ones produced using the other rolling regimes. The average density of the cores compacted using the D-T rolling regime were about 30 kg/m^3 higher than those produced in the other regimes (see Fig. 5). Again, the variability within a slab was high, although the densities in the middle part of a slab were rather constant with the difference between the minimum and maximum densities no more than 25 kg/m^3.

ITS tests were then performed to complete the experiment. With the largest differences in density being discounted by selecting only the middle cores of the slabs, there seems to be a



Figures 5 and 6. Average density. Average fracture energy.
*D and T indicate the roller type (three-drum (D) and tandem (T)) and the numbers correspond to the slab number.

relationship between ITS and the rolling regime. The ITS of the cores compacted using the D-T rolling regime were about 10% lower than the cores compacted using the other rolling regimes (see Fig. 6). A possible explanation is that the three-drum roller is too heavy and so creates micro-cracks at the high temperature of 150 °C. However, this hypothesis needs to be confirmed or rejected in other laboratories.

6 DISCUSSION AND FUTURE RESEARCH

Although we have succeeded in simulating the asphalt cooling process in laboratory compaction procedures, there are still various points to address. First, we have seen that there is still significant variability in both density and Indirect Tensile Strength (ITS) within the asphalt slabs. As such, the procedures need to be improved to reduce the variability in density. Possibly, this could be achieved by automating the filling of the mold with the asphalt mixture related to the pre-compaction of the paver. Further, the variability in ITS values has a strong influence on the ratio between the dry and retained values (ITSR), and this makes the ITSR an even more unreliable parameter for use in analysis and comparison. A final concern is that the ITS test may not be sufficient to observe differences between slabs that were compacted within different temperature windows. In future research it may therefore be valuable to test cores using other mechanical tests such as the triaxial test or the four-point bending test. Also, additional research could usefully be devoted to further experimenting with different roller regimes, and specifically with more critical mixtures when it comes to compaction, such as thin surfaces. In case of using asphalt mixtures with multiple aggregate sources, it may be better to evaluate the air voids rather than the density. Further, more extreme loads could be tried to determine when micro-cracks due to roller loads may arise. We also plan to explore other variables in the compaction process, such as the timing of the first roller pass and the effect of roller speed, and to determine the effects of additional roller passes once the target density is achieved.

Finally, it is important to validate the experimental results obtained in the laboratory with field experiments. Therefore, further research effort is planned that involves designing a field experiment in which a rolling strategy will be given to roller operators and its implementation monitored using GPS equipment. Following this, the rolling process will be closely simulated in the laboratory and the resulting mechanical properties compared.

7 CONCLUSIONS

The significance of appropriate rolling and compaction for road quality is widely acknowledged and improved process and quality control are vital. However, procedures to design or specify compaction processes are lacking and thus also methods to provide appropriate instructions for roller operators. Existing laboratory procedures generate a single 'ideal' compaction temperature based on the binder viscosity, while in practice roller operators have to select and work within windows based on time and temperature. This paper has described initial work to include asphalt cooling and rolling regimes in laboratory compaction procedures. Typical field compaction processes for an AC 16 base/bind and for an SMA 11 surf were simulated in the laboratory within different temperature windows by applying specified rolling regimes using a slab compactor and a 2.5 ton roller. In this initial stage, we succeeded in imitating, in the laboratory, field compaction processes in terms of temperature windows and rolling regimes. By following a standard procedure, it was possible to conduct roller passes at various temperatures and so compact the asphalt within a specified temperature window.

Using the AC16 base/bind, three temperature compaction windows were experimented with: from 140 down to 70 °C, 120–60 °C, and 120–40 °C. None of these tests suggested a significant and consistent relationship between temperature window and final density and Indirect Tensile Strength. Similarly, two temperature windows were used with the SMA 11 surf mixture, from 150 °C down to 50 °C and 120–40 °C. With this mixture, the slabs compacted in the cooler temperature window were less dense, typically by 30 kg/m^3. When the differences in density were discounted, the slabs compacted in the lower temperature window have Indirect Tensile Strengths (ITS) that are about 10% higher. In a final set of experiments, the rolling regime for the SMA 11 surf was varied. Three regimes were tested: (1) first a three-drum roller and then a tandem roller, (2) first a tandem roller and then a three-drum roller, and finally (3) two successive tandem rollers after each other. The slabs compacted using the first roller regime with a three-drum roller followed by a tandem roller were about 30 kg/m^3 higher in density. However, the ITS of the slabs compacted using this roller regime were about 10% lower.

The results demonstrate that it is certainly important to specify rolling strategies based on temperature windows that depend on the asphalt mixture. If an SMA 11 surf is compacted outside the optimal temperature window, or using a sub-optimal rolling strategy, the density may drop by 30 kg/m^3 and the Indirect Tensile Strength by up to 10%. These experimental results could help in designing appropriate rolling regimes and providing better instructions to roller operators. The results reflect a step forward in diminishing the gap between field and laboratory compaction outcomes. Further research effort will be put into verifying the results under in-situ conditions. Overall, the results are a valuable step in the quest for improved process and quality control.

ACKNOWLEDGEMENTS

This research would not have been possible without the cooperation provided within the ASPARi network. We would especially like to acknowledge the eleven contractors for the opportunity to conduct research at their construction sites and in their laboratories.

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