Asphalt Production at Reduced Temperatures and the Impact on Asphalt Performance

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ABSTRACT: Everybody is well aware of the environmental benefits of reducing temperatures in asphalt production and paving, but how to achieve this while maintaining the same high performance standards for the asphalt pavement is a question that is not yet fully answered. Nynas and the Belgian Road Research Centre collaborated in a research project, involving some of the most important and promising technologies for reducing production temperatures: addition of waxes, addition of zeolites and the use of foamed bitumen. The first part of the project was dedicated to a laboratory study. Mixing, compaction and testing procedures were optimized and the ranges of temperature reduction were determined with respect to workability and compactability. The performance of the asphalt produced at reduced temperatures was compared to the performance of the corresponding hot mix asphalt on the basis of permanent deformation, water sensitivity and thermal cracking. In the second part of the project, field trials were organized in two phases. In the first phase, test sections were made on the site of the asphalt production plant, to gain experience and know-how on production and field compaction. A large number of asphalt samples were cored from these "internal" test sections, to validate the laboratory performance tests and the conclusions drawn from the laboratory study. In the second phase, the techniques were applied on a public road. Here also, production and compaction were monitored and samples were taken for laboratory analysis. In addition, the public road sections will make it possible to follow the long term behaviour of reduced temperature asphalt.

KEY WORDS: Asphalt performance, temperature reduction, wax, zeolites, foamed bitumen.

1 INTRODUCTION

For more than a century now, the usual production temperatures of hot mix asphalt have been in the range of 150 to 190°C, varying according to the binder and the mix type. Such high temperatures ensure complete drying of the mineral aggregates and lower the viscosity of the binder, resulting in good aggregate coating, workability and compaction. All of these factors contribute to a high-performance and durable asphalt pavement. In the last years, environmental awareness is forcing the industry to explore all possible ways to mitigate the environmental impact of industrial processes. For asphalt production, consumption of fossil fuels and emission of greenhouse gasses need to be reduced and lowering the production temperatures is the most straightforward way to do this. At the same time, safety and working conditions of the people at the plant and on the work site can be improved. Several techniques and additives are being proposed to lower the production temperatures:

- by lowering the viscosity of the binder in the high temperature range;
- by creating a lubricating effect (e.g. foaming);
- by making bitumen fluid (e.g. emulsification);
- by modifying the mixing sequence, etc.

Many techniques can also be combined, offering a wide range of possible solutions.

2 RESEARCH OBJECTIVES

The aim of the present research project was to study the performance and the durability of asphalt produced at lower temperatures. If the temperature reduction would result in a lower quality pavement, the environmental benefits would be zero or negative on the long term as the pavement would need to be repaired or replaced more frequently. Therefore, it is imperative that an asphalt mix produced at lower temperatures meets the same high standards as the equivalent asphalt mix produced at normal hot temperatures.

This research project consisted of a laboratory study and a field study. The laboratory study aimed at developing or optimizing test procedures, to allow for the laboratory evaluation of the performance of asphalt produced at lower temperatures. This is very important as part of developing type testing procedures for these types of mixes. The laboratory tests were then used to study the performance of asphalt produced at reduced temperatures, using the techniques described in the following section, and to compare it to the hot mix asphalt with the same composition. The field study served two main goals: first, to validate the results and conclusions of the laboratory work and second, to gain practical experience with large scale production and paving at reduced temperatures.

3 STUDIED TECHNIQUES

The project focused on three representative and distinctive techniques:

3.1 Addition of waxes

Waxes with a melting range between 80 and 120 °C are capable of lowering the viscosity of the binder in the high temperature range, when they are in the molten phase. At service temperature, when the wax has crystallized, the wax modified binder has a higher stiffness and viscosity than the base binder. Provided the crystallization temperature is above the high service temperature range, waxes are also expected to improve stiffness and rut resistance.

3.2 Addition of zeolites

Zeolites are aluminum silicates, capable of storing a large amount of water within their crystal structure. When they are added to an asphalt mix above 100 °C, they gradually release vapour, which induces a controlled foaming effect in the binder. Workability and compactability are thereby improved, so that the production temperature can be reduced.

3.3 Bitumen foaming

Foaming the binder temporarily increases its volume and creates a lubricating effect, which makes it possible to produce the mix at lower temperature. The binder is foamed in a foaming unit, where a small quantity of water and compressed air are mixed with the binder. By releasing the pressure through a specially designed nozzle, the volume of the binder is expanded, before it is added to the aggregates. The aggregates also need to contain a small but sufficient amount of water to sustain the workability while the foam collapses. Consequently, the production temperature has to remain below 100 °C and the reduction in energy consumption and emissions is more important than for the two previous techniques.

4 LABORATORY STUDY

One single type of asphalt mix was used in this study: a dense asphalt concrete 0/10 for top layers, frequently used in Belgian practice. The hot compaction temperature of this mix is 150 °C, the mixing temperature varies from 160 to 170 °C. The performance characteristics of the hot mix were considered as the reference throughout the study. With the first two techniques (waxes and zeolites), a temperature reduction of approximately 30 °C was expected. For the third technique, the production temperature was 90 °C, so a reduction of 60 °C was achieved.

4.1 Preliminary tests

At the start of the project, a range of candidate products for reducing the production temperature (waxes and zeolites) were collected. Preliminary tests were conducted on these products for selecting the most suitable ones for obtaining a sufficient temperature reduction.

For the waxes, these tests included DSC (Differential Scanning Calorimetry) heating and cooling scans, to study the melting and crystallization behaviour, and DSR (dynamic shear rheometry), to study stiffness and viscosity versus temperature for wax-binder mixtures in various proportions (Soenen, 2008). The tests revealed important characteristics on which the selection of the wax, the base binder and the proportion wax/binder was based. An important conclusion drawn from these preliminary tests was that, to obtain a significant reduction of the temperature, the wax has to be used in combination with a softer base binder. Even then, viscosity tests indicated a possible temperature reduction of 15 °C at most. DSR measurements indicated that using a softer base binder does not adversely affect the stiffness and viscosity at high service temperatures, because waxes have a stiffening effect in that temperature range. Consequently, no higher rutting levels were expected, but this had to be verified by means of rutting tests on the asphalt mix (see 4.4).

For the zeolites, the selection was made on the basis of the maximum moisture content, which depends on the type of zeolite and the environmental conditions of storage. Moisture content is an important parameter: the higher the water content, the less additive needs to be used for the same foaming effect. The tests on zeolites are described in (De Visscher, 2008).

For the foam technique, adhesion improvers were added to the filler fraction. Two types were considered; they were directly studied as part of the asphalt tests.

4.2 Workability

Workability is generally not an issue for hot mix asphalt, but when exploring the lower temperature limit for production, workability becomes more critical and we need to verify whether it is still acceptable. Workability tests were carried out with the “Nynas workability tester” (Gustavsson, 1996), initially developed to test the workability of cold mixtures. It was found that lowering the production temperature of the reference mix by 30 °C had no significant effect on the test results. The conclusion was that workability is most likely not a limiting factor for the temperature reduction.

4.3 Compactability

Poor compaction leads to inferior performance, e.g. more rutting due to post-compaction by traffic, more water sensitivity due to the higher void content and faster oxidative ageing. Using heavier compaction equipment on site is not a solution, since this may result in other problems, like compaction-induced cracking. Therefore, the compactability of the mix produced at lower temperature must equal that of the hot reference mix. To study the compactability as function of compaction temperature, a gyratory compactor was used (EN 12697-31). Even though the differences in void content were small, clear trends could be observed and interesting conclusions could be drawn.

The left hand graph in figure 1 shows as an example the void content at 200 gyrations as function of the compaction temperature, for the reference mix with a B50/70 binder and for the mix with a softer base binder and 3 % wax on the binder mass. Each result is the average of three tests and the standard deviations are also plotted. The graph shows that the void content increases when compaction temperature is reduced. Using a softer base binder with wax has a minor effect: at 135 °C, the compaction is slightly better. Although the effect is small, it agrees with the viscosity tests made on the B50/70 binder and the wax modified B70/100 binder: these tests also indicated a possible temperature reduction of about 15 °C.

The right hand graph shows results for mixtures with zeolites. It is observed that the use of zeolites systematically leads to a lower void content. For the type of zeolite used in this test, it is said in the technical sheet that a temperature reduction of 30 °C can be achieved with 0.3 % of the product added on the mass of the mix. This is confirmed by figure 1, as the void content at 120 °C with zeolites is the same as the void content of the reference mix at 150 °C, within the precision of the tests. Doubling the amount of zeolites improves the compactability even more, but doesn't allow to reduce the temperature further down to for example 105 °C. Consequently, the additional cost of a higher amount of zeolites is not justified.

For zeolites, the gyratory compactor was also used for evaluating the impact of other parameters (De Visscher, 2008). Only the main conclusions are summarized here:

- The degree of compaction decreases when the time between mixing and compaction increases. In the end, the same void content is obtained as for the reference mix, when compacted at lower temperature. This shows that the time period shall be kept as short as possible, in order to get the maximum efficiency from the zeolites.
- The highest levels of compaction were achieved with the zeolite with the highest moisture content and the finest grading.

For the mix with foam bitumen, gyratory compaction tests were used to evaluate the impact of foaming or not foaming, the time between mixing and compaction, the initial moisture content of the aggregates (1 % and 2.5 % on the aggregate mass just before mixing) and the type of active filler (Soenen, 2009). The main conclusions were:

- Foaming the bitumen had little impact on the compactability, compared to adding hot bitumen (but it had an important effect on the performance of the compacted mix).
- The degree of compaction decreases when the mix is stored for longer times (at 90°C) before compacting it.
- With 1% of initial moisture content, the same degree of compaction could be reached as with 2.5 %, but the time window was reduced.
- No clear effects could be observed on the degree of compaction from the use of an active filler or the type of active filler (but using an active filler improves the performance of the compacted mix).

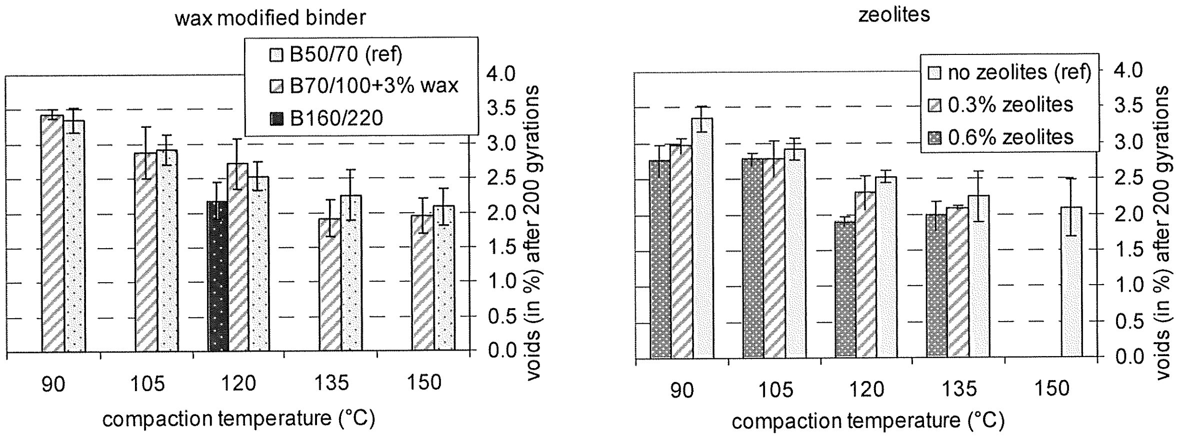

Figure 1: Void content after 200 gyrations, at various compaction temperatures

4.4 Rutting

Rutting was evaluated by means of wheeltracking tests (EN 12697-22, large size device). It was mainly a concern for the mixes prepared with wax modified binders. As already discussed, a softer base binder is needed to achieve a sufficient temperature reduction, so rutting may become critical. Figure 2 shows results for the reference mix with a B50/70 binder, at various compaction temperatures, and three combinations of a softer binder with wax. The reference mix shows more rutting when compacted at too low temperature, which is probably a consequence of post-compaction. The combinations of a softer base binder with wax perform well up to a certain limit: using an extremely soft binder obviously leads to early rutting. The combination of the binder B70/100 with 3 % of wax, compacted at 135 °C, shows the same rutting as the reference mix, compacted at 150 °C.

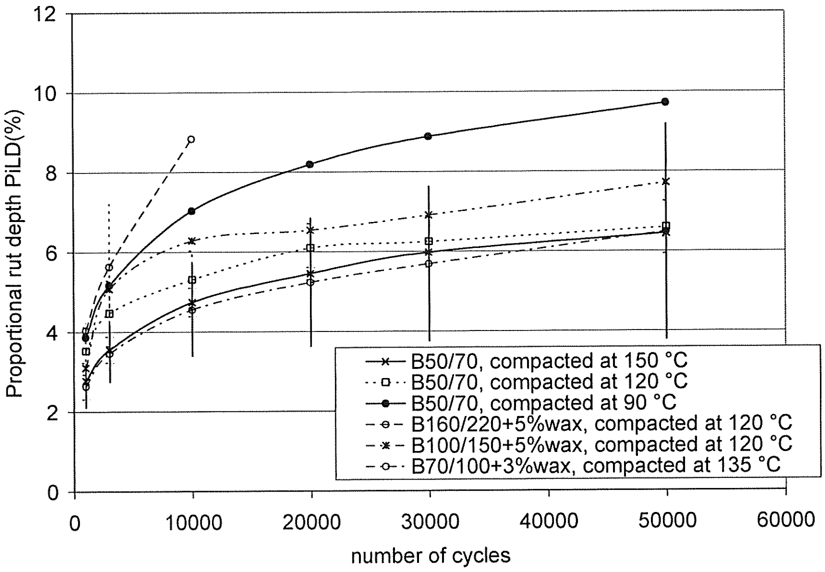

Figure 2: Wheel tracking tests for reference mix and mixes with wax modified binders

The rutting tests with zeolites confirmed the assumption that the addition of zeolites does not affect rutting, as long as the mix is properly compacted. For the mixes with foamed bitumen, it was decided to verify the rutting resistance at a later stage, directly on material extracted from test sections.

4.5 Water sensitivity

Water sensitivity was evaluated by means of the Indirect Tensile Strength (EN 12697-23), before and after water conditioning (EN 12697-12). Poor coating of the aggregates and insufficient compaction are known to have an impact on water sensitivity, so this test is considered as essential for the evaluation of asphalt produced at reduced temperature.

The Indirect Tensile Strength Ratio (ITSR) was measured at 15 °C. The gyratory specimens were compacted to 25 gyrations, simulating a field situation with low compaction. As expected, a decrease of the compaction temperature corresponds to a decrease of ITSR, or more water sensitivity. Figure 3 show that using waxes or zeolites has a positive effect at lower compaction temperatures. In other words, the compaction temperature can be decreased while maintaining the same ITSR as the hot reference mix.

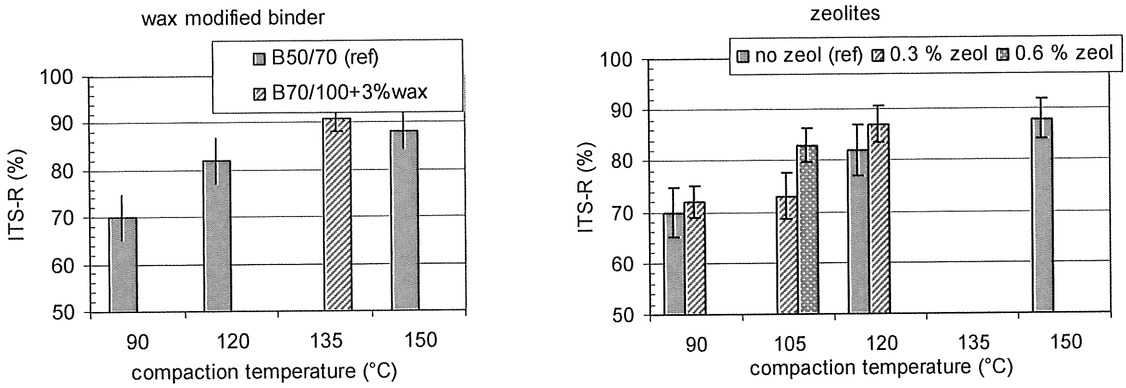

Figure 3: ITSR for various compaction temperatures using wax (left) and zeolites (right)

The mixtures with foamed bitumen require special consideration in the context of water sensitivity, as the mixtures are prepared with aggregates that contain an initial amount of moisture. The tests confirmed that ITSR of this mixture was lower, compared to the hot reference mix. But when the test specimens were stored for a period before doing the tests, ITSR increased. This corresponds to a loss of weight, due to water evaporation from the specimens. It shows that the mixture needs a "curing time", before attaining its final performance characteristics. The final ITSR value satisfies the current specifications for this mix type in Belgium (>70 %), but the value of the hot reference mix (88 %) was not achieved.

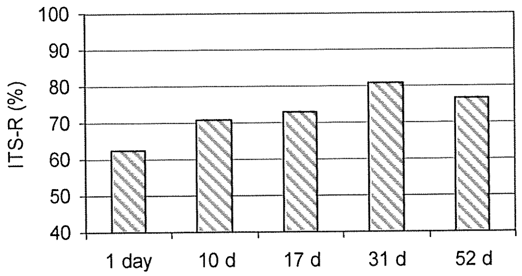

Figure 4: Increase of ITSR of foamed bitumen mixtures

4.6 Low temperature cracking

The sensitivity to low temperature cracking was evaluated by the Thermal Stress Restrained Specimen Test (TSRST), following prEN 12697-46. Upon cooling, the stress in the restrained specimen increases up to the cracking stress. At least three specimens were tested per mix to obtain an average result. The temperature at which the crack appeared was not significantly higher for the mixtures prepared at reduced temperature (see table 1). The cracking temperature was even lower for the mix with wax, while the opposite is often feared.

4.7 Summary of results for test section variants

The best way to compare different variants is to apply them all on the same test tracks, under equal conditions, as described in the following paragraph. At this moment, only the two first techniques (waxes and zeolites) have been applied on test sections, as the unit for producing foam was not yet installed at the plant. The hot mix was always included as a reference section. For comparison, table 1 summarizes the performance characteristics measured in the laboratory study on the three variants applied on the test sections.

Table 1: Overview of laboratory tests on test section variants

	Reference hot mix	Mix with wax	Mix with zeolites
binder pen grade	B50/70	B70/100	B50/70
additive	/	3 % wax by mass on the binder	0.3 % zeolites by mass on the mix
lab compaction temperature	150 °C	135 °C	120 °C
P_{LD} (30000 cycles, 50 °C)	6.0 %	5.7 %	5.7 %
TSRST cracking temp.	-24.4 °C	-25.9 °C	-22.0 °C
ITSR (15 °C)	88 %	91 %	87 %

5 TEST SECTIONS

The laboratory tests allowed to compare the performance of the mixtures, when prepared and compacted in controlled laboratory conditions, starting from perfectly dried aggregates (or with a controlled moisture content in case of the foam technique) and with a short time between mixing and compaction. A few experiments were made to estimate the impact of non-ideal conditions, such as wet aggregates or longer waiting times, but these experiments were limited. Organizing test sections was therefore considered as an essential subsequent step to validate the results in real conditions and to gain experience with production in an asphalt plant, paving and field compaction.

5.1 Internal test sections

In a first phase, small scale internal test sections of 30 m length per variant were constructed on the site of the asphalt production plant. All the parameters of the production and compaction process were closely monitored. The aim was to compact the reference hot mix at 150 °C and the two other variants at 120 °C. Although the mix with wax had always been compacted at 135 °C in the laboratory study, the good test results justified the attempt to lower the temperature also to 120 °C. The production temperatures were tuned until the temperatures of the mixtures were 10 °C higher than the target compaction temperatures. Table 2 shows the temperatures measured with an infrared temperature probe just behind the finisher. The measured values were generally lower than the target compaction temperatures, except for the 3rd section, where the average was just at the right temperature. Paving and compacting took place under practically equal weather conditions, as the three sections were

all paved in a short time frame, between 4 and 7 pm. The compaction process was monitored on site using a nuclear density probe, in two points per section. All sections could be compacted equally well. Table 3 shows the final density measurements and the number of roller passes and time needed. There are no significant differences between the three sections. Asphalt specimens were cored to repeat the tests for rutting and water sensitivity. Table 4 shows the results, compared to the results from the initial laboratory study (between brackets). The variation in bulk density in a pavement is larger than in laboratory compacted specimens and consequently, the variation in test results on asphalt samples from a pavement is also larger. Particularly ITSR is very sensitive to void content. Therefore, the density was first measured with a nuclear probe in 10 points per section. The ITSR results shown in table 4 were measured on a series of cores, taken in pairs near the 3 points with the lowest bulk density (highest void content). Another series was taken near the 3 points with the highest bulk density, but these test results are less discriminating and not included in the table.
The following conclusions can be drawn:

- The rut depth measured on specimens from the sections is larger for the reference mix and the mix with zeolites, but smaller for the mix with wax. The differences are however not significant and all results fall in the same category (5 % $<P_{LD}\leq$ 10 %).
- Compared to the initial laboratory study, the decrease in ITSR is largest for both mixtures produced at reduced temperatures, but all results are still rather good (ITSR≥70 %).

Table 2: Temperatures measured behind the finisher (with IR temperature probe)

	Section 1 (reference)	Section 2 (zeolites)	Section 3 (wax)
min-max	132-148 °C	111-117 °C	117-123 °C
average	141 °C	114 °C	120 °C

Table 3: Summary of the compaction process

	Section 1 (reference)		Section 2 (zeolites)		Section 3 (wax)	
	position 1	position 2	position 1	position 2	position 1	position 2
density (g/cm³)	2.34±0.02	2.35±0.02	2.30±0.01	2.32±0.02	2.32±0.02	2.38±0.01
roller passes	14-16	13-14	13-14	11-12	14-16	12-14
time (min)	25±5	20±5	15±5	13±5	17±5	15±2

Table 4: Performance tests on specimens cored from test sections (the values between brackets are the results obtained on the laboratory prepared specimens)

	Reference hot mix	Mix with wax	Mix with zeolites
P_{LD} (30000 cycles, 50 °C)	9.3 % (6.0 %)	4.7 % (5.7 %)	8.7 % (5.7 %)
ITSR (15 °C)	85 % (88 %)	82 % (91 %)	74 % (87 %)

5.2 Public road sections

Encouraged by the positive experience with the internal sections, the first public road sections were constructed on the N436 (in Assenede) in april 2009. The larger production volumes (each section was 300 m long and 6 m wide), the longer distance from the plant (35 km, corresponding to approximately half an hour) and the more realistic compaction process were additional parameters that could have an impact on the final performance characteristics of the pavement. Paving started at 7 am with the mix with zeolites and ended in the afternoon with the mix with wax. In contrast to the internal sections, the conditions changed more drastically from section to section: at 7 am, the temperature was only 7 °C, but due to the sunny weather the temperature went up to 20 °C by noon. Direct sunlight also implied significant heating of the base layer, slowing down the cooling process of the newly laid surface layer.

Figure 5: Paving of test tracks and nuclear density measurements during compaction

Table 5 shows the temperatures measured just behind the finisher. These were very close to the target temperatures for sections 2 and 3, but slightly too low for the first section. Table 6 shows the parameters of the compaction process, followed in one point per section. There are some differences which could be explained by the variation in environmental conditions: section 1 was placed at the lowest temperature (both mix temperature and environmental temperature), while section 3 was placed at the highest environmental temperature. Table 7 shows the results on the specimens cored from the test sections, compared to the laboratory study (between brackets). There is more rutting for the sections produced at lower temperature, but considering the repeatability of the test on cored specimens, it is not yet possible to draw general conclusions from this observation. ITSR results agree with the internal test sections, they are even higher for sections 2 and 3.

Table 5: Temperatures measured behind the finisher (with IR temperature probe)

	Section 1 (zeolites)	Section 2 (reference)	Section 3 (wax)
min-max	99-120 °C	142-157 °C	117-127 °C
average	113 °C	148 °C	120 °C

Table 6: Summary of the compaction process

	Section 1 (zeolites)	Section 2 (reference)	Section 3 (wax)
density (g/cm³)	2.28±0.02	2.30±0.02	2.36±0.02
roller passes	14-16	12-14	18-20
time (min)	25±5	25±5	45±5

Table 7: Performance tests on specimens cored from test sections (the values between brackets are the results obtained on the laboratory prepared specimens)

	Reference hot mix	Mix with wax	Mix with zeolites
P_{LD} (30000 cycles, 50 °C)	6.7 % (6.0 %)	10.5 % (5.7 %)	11.7 % (5.7 %)
ITSR (15 °C)	94 % (88 %)	92 % (91 %)	76 % (87 %)

The long term behaviour of the sections will follow from inspections that will be performed twice a year. In october 2009, the test sections were inspected for the first time: there were no signs yet of rutting, cracking or any other type of damage.

6 CONCLUSIONS

The project described in this paper studied the performance of asphalt produced at reduced temperatures. Reducing the production temperature seems very promising from an ecological point of view, but it is essential that the usual high pavement quality can be maintained. Focusing on three different techniques, it was shown how laboratory test procedures can assess the limits of the temperature reduction for a particular technique. Gyratory compaction plays a special role in this procedure, as a poorly compacted mix will inevitably lead to inferior performance. Two of the techniques (waxes and zeolites) can be assessed in the laboratory without any major complications. A temperature reduction of 30 °C could be achieved with both techniques (for the mix and the materials used in this study). These techniques have been successfully applied on test sections. The follow-up of the long term behaviour of the sections on a public road will provide additional information on the most important issue of durability. The technique with the highest temperature reduction (foam technique) also presents the highest difficulties to study in the laboratory, the largest modifications to the asphalt plant and probably also the highest risks.

Although far from complete (products and techniques are being improved or developed continuously), the project shows how the temperature reduction can be studied in the laboratory, offering the best chances of successful application on the road.

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