OPERATIONAL BEHAVIOR AND PERFORMANCE OF LABORATORY AND FIELD PRODUCED WMA ASPHALT

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ABSTRACT: Governments, regulation and road authorities push more and more for sustainability. Contractors respond with strategies to reduce their carbon footprint. One tendency is to reduce the production temperature, known as Warm Mix Asphalt (WMA). This paper hones in to this tendency and evaluates the consequences in terms of operational behavior and performance of one of the three options the literature points to, namely the addition a Zeolite (Advera). To study this behavior and performance, we [1] conducted experiments to study the performance in the laboratory, [2] studied the effects of the moment of mixing the additive within the mixture during a field study, and [3] studied the resulting mechanical properties in a field study. The results of the laboratory experiments and the field studies show that the performance of this WMA can be comparable with a HMA. However, the results for the resistance against rutting (fc) show much variability. Additionally, the operational behavior using this WMA shows a lot of variability in mixture temperature and compaction strategy. WMA seems more vulnerable for this variability in operational behaviour than HMA, especially for the resistance against rutting. From a production point of view, adding the additive in the production phase is good possible and seems not very vulnerable for a different moment of dosing the additive. So, the process seems quite robust. The results of this study help designers, planners and project managers towards better informed decisions about the use of WMA related to specific project conditions.

1. INTRODUCTION

The last thirty – forty years, in the beginning slowly and later on more rapidly, society became aware of the susceptibility of our earth in terms of climate, pollution and other factors that threat livability on earth. In the last millennium we experienced the industrial revolution. Economical welfare raised enormous however the negative effects were also not little. We now struggle with these effects, how should we (re-)act, how can we act to preserve our planet to guarantee livability of our planet for next generations?

As a result of the increase of that awareness the last years, energy expenditure, use of fossil fuels and CO_2 emissions have become a main concern to industries, societies and governments. This concern applies heavily to the road paving industries since the production and application of hot asphalt mixtures consumes important amounts of energy (Grampre et al, 2008). Ordinary asphalt mixtures are produced at temperatures of about 150 till over 180 ˚C, only to reach a good coverage of the aggregate particles. If we would be able to reach this wetting at lower temperatures we would save lots of energy and emissions. For instance the world bank indicated that for every 10 ˚C decrease in production temperature, savings of nearly 1 L fuel oil and 1 kg of CO_2 emissions are realized per ton of mix produced asphalt (Hanz et al, 2010).

Reducing production and placing temperatures has also other positive side-effects: Lower production temperatures for asphalt paving mixtures will decrease the aging of the asphalt binder during production. This limited aging can improve thermal and fatigue cracking resistance (Hanz et al, 2010, Silva et al, 2010). Further, do reduced production and placing temperatures of asphalt mixes, lead to reduced emissions, fumes, and odours, cooler work environment, and, off course, energy savings (Silva et al, 2010). An advantage of WMA instead of HMA is also a better health for contractors and public (Zhanping, 2011).

Then, lower production temperatures also implicate that in most of the times lay down operations of the asphalt mixture and final compaction must be achieved at lower temperatures. This asks for a better workability of the mix at lower temperatures. Most of the additives and procedures indicate that lower production temperatures also work on the workability during the paving operations on site. Such a workability improvement has benefits: higher in-place density and reduction the permeability of the Warm Mixed Asphalt (WMA). Side effects are that improved workability also has the potential to extend the construction season and the time available for the placement of the asphalt mixture during a certain day.

Altogether can be concluded that lower production and paving temperatures have lots of advantages, mostly relating to sustainability, this is a good reason for contractors to further study the possibilities of such materials. Thus, reducing the production temperature of asphalt mixtures has several advantages. Therefore, it is important to study the opportunities of reducing this production temperature and evaluate the performance and operational behavior. In the next paragraph we discuss the research methodology we followed to create more insight in this performance and behavior.

2. RESEARCH METHODOLOGY

This paper hones in to the quest for reducing the production temperature of asphalt mixtures. In this paper, we addressed the consequences of reducing this production temperature for [1] performance in the laboratory, [2] robustness of the production process for different moments of adding the additives, and [3] operational behavior and resulting field properties. Additionally, we reflected on the use of RAP in the WMA and the amount of the additive.

To study these consequences, we chose for the following research methodology, which is also the structure of the proceeding of this paper:

1. A literature review to study the various options to produce asphalt mixtures at lower production temperatures;
2. Making lab samples and testing them to test mixing procedures and performance;
3. Two full scale field test sections to test various moments of adding the additive and make field produced asphalt samples;
4. Testing the mechanical properties of the gathered full size samples from the field studies.

With the results of this study we plan to help designers, planners and project managers to make better informed decisions about the use of WMA, also related to specific project conditions.

3. BACKGROUND STUDY WARM MIXED ASPHALTS

3.1Production of Warm Mix Asphalt (WMA)

Reduction of the production temperature of asphalt mixes can be realized by globally three phenomena (Hanz et al. 2010, FHWA 2008):

a. viscosity reduction of the bitumen through the use of a wax (organic additive) based or chemical additive,
b. foaming the bitumen by adding an hydrophilic additive to the mix (Zeolite) or by injection of water vapor into the mix, or,
c. reduce the internal friction by adding a (chemical) surfactant .

According to manufacturer recommendations most of the proposed additives should lower the mixing (production) temperatures ranging from 110 – 135˚C (FHA 2007).

Another way to classify WMA technologies is the degree of temperature reduction during production. Figure 1 shows classification of various application temperatures for asphalt concrete from cold mix to hot mix.

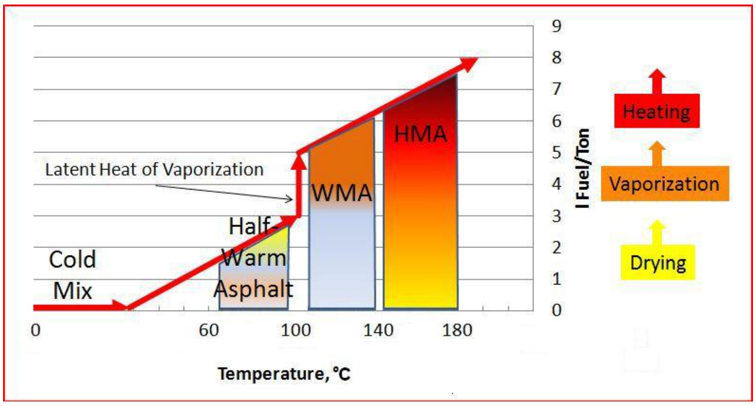


Figure 1: Classification Temperature Range Cold until Hot Mixed Asphalt (Zaumanis 2010).

The next sections describe how we can reduce the production temperature.

Organic additives

The processes that uses organic additives (e.g. Fisher-Tropsch wax, Montan Wax or Fetty amides) show a decrease in viscosity above the melting point of the wax. Such a type of wax should be selected carefully in such a way that the melting point of the wax is higher than the in-service temperature of the designed asphalt pavement (FHWM 2008). Otherwise the mixture is to week/soft during the in-service conditions. Examples of wax additives are: Sasobit, Ecoflex, Licomont and Asphatan B (Ball 2010).

Foamed bitumen types

The foamed bitumen types, rely on the fact that when a given volume of water turns to steam at atmospheric pressure, it expands by a factor of 1.673. When the water turns to steam it results in an expansion of the binder phase and this results into a viscosity reduction of the binder in the mix. (FHWM 2008). There are different ways to get the water (steam) into the mix. One can directly water inject into (a part of) the (hard) hot bitumen creating foam bitumen in combination with a soft (penetration) bitumen added earlier to the mix. Examples are the WAM Foam process (Roberts 2007) and the Low Energy Asphalt (LEA) process (Louslau 2007). Apart form that it is also possible to add a Zeolite additive directly to the mix while mixing just like the filler. Examples of Zeolite suitable for producing WMA are Advera and Aspha-min.

Use chemical additives

A quite novel approach in order to make (produce) WMA is using chemical additives pre-mixed into the bitumen. By using the bitumen in which the Cesabase is added one is able to produce (mix) WMA at a temperature of 120˚C. (Grampre 2010). The here mentioned Cecabase RT is a brand name. There different brands of chemical additives exists e.g. Cecabase RT, Rediset WMX, REVIX and Evotherm 3G.

A common theme while studying the effects of different mixture production methods is that making use of the additives and lowering production temperature will not affect the asphalt binder performance properties negatively. Although an exception on this statement is the use of the wax based viscosity reducer Sasobit (Sasobit improves the high temperature susceptibility of the mix positively) (Hanz 2010).

Further studies, done after the performance of asphalt mixtures produced at lower temperatures, indicate that any impact of WMA on performance observed in the lab result are due to reduced binder aging, not the presence of the WMA additive.
It is concluded that the high temperature performance of mixtures become more critical (rutting!) when considering the impacts of reduced production temperatures (apart form Sasobit) (Hanz 2010).

4. EMPERICAL TESTING PROGRAM:

Within the first section 4.1 “empirical testing” we focus on different phases during the empirical test program: we start with the laboratory tests that have been done on Marshall compacted lab samples. After that in section 4.2 we discuss paving the full scale test sections, performed at the asphalt plants Heerenveen and Hengelo. We focus on measurements done during the mixing and paving stage. Our main interest concerns temperature of the mix related to workability and compactibility. In the last section, 4.3 we discuss the tests results from samples taken from the full scale test sections, and on results from lab samples prepared using the plant mixed mixture. Tests done on those samples are Tri-axial testing and Four point bending tests (fatigue).

4.1. Pre-pilot Lab research:

During the literature research we focused on different additives to produce WMA mixtures. Aspects that we took into account were:

- The maturity of the different products and/or procedures, how often asphalt mixtures have been produced using the additive and/or production methods.
- The suitability or the REEF asphalt production plants in relation to the additive and or procedure.
- Flexibility of the use of the product at the production plant. Can it be implemented if only a limited part of the production plant capacity produces WMA instead of HMA?
- The expected performance of the warm produced asphalt mixture.

At a first step the material lab samples were made and the indirect tensile strength (ITS) is deduced. Samples were tested “dry” and “retained” (CROW, 2010). The difference in indirect tensile strengths “wet” and “dry” is known as ITSR value. The ITSR value gives an indication of the water sensibility of the asphalt mixture. For testing the workability of the mixtures the Voids percentage of produced samples were measured. The preparation of the Marshall compacted test samples started at an asphalt temperature of 130˚C. At the first phase of the testing program the following additives were tested:

- Sasobit (Wax),
- Cecabase RT (Chemical additive),
- Rediset WMX (Chemical additive),
- Advera (Zeolite).

We did some first (limited) experiments using different types of additives and did a literature study to see what the strong and weak aspects are of the different ways to make WMA. Based on that we made the choice to do further tests using the a zeolite named Advera. A consideration for using the additive Advera, is they way a zeolite can be added to the mixture. Chemical additives must be mixed in into the bitumen. In such a case one has to take at least a separate storage facility for the bitumen with the add. The zeolite is a powder that can be dry added to the mixing drum, just like a filler. This implies that a dosage installation for the additive is needed but this is not to difficult. An important advantage however, is that the asphalt plant is relatively flexible to switch between producing WMA and HMA mixtures at one and a same day.

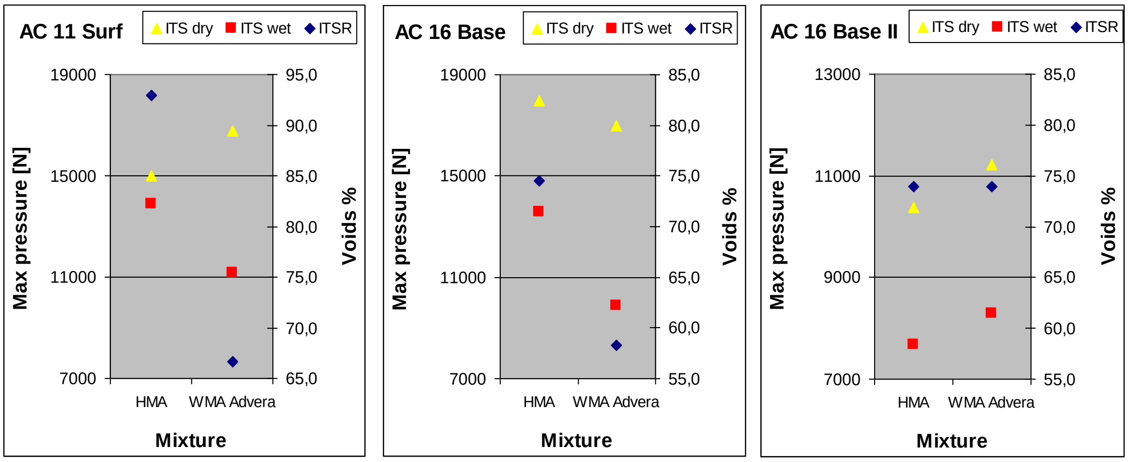
Apart from that we want to mention the good results achieved using a zeolite in order to produce WMA. Already in 2007 300.000 tons of WMA had been produced worldwide using a zeolite as add (Prowell 2007).

Asphalt types AC 16 Surf, AC 16 Bind and AC 22 Base, have been tested respectively with 0, 30 and 50 per cent of RAP. Table 1 and figure 3 show the results gathered from tested WMA samples prepared using Advera compared to HMA samples prepared at 170 ˚C.

The results show that the WMA Advera prepared samples sometimes perform slightly worse, perform sometimes more or less equal and perform sometimes better in relation to comparable HMA samples. The dry ITS values are better in situations a and c (figure 3) and slightly worse in b. The wet ITS values are significant lower in situations a and b but better in situation c related to HMA. The voids percentage is however in all situations more or less comparable (no big difference, see table 1). ITSR values are significantly lower in situations a and b but more or less equal in situation c (figure 3). Mixtures b and c do have the same composition but are prepared using bitumen from a different origin and different fillers.

Table 1. Voids percentage of the lab test samples WMA Advera versus HMA.

Voids % results WMA Advera AC 11 Surf compared to HMA AC 11 Surf		
	HMA	WMA Advera
AC 11 Surf (a) [%]	2.1	2.9
AC 16 Base (b) [%]	5.1	4.8
AC 16 Base II (c) [%]	3.3	3.6



(a) (b) (c)

Figure 2. Most important parameters out of lab testing on AC 11 Surf (a) and Ac 16 Base (b) & (c), WMA Advera versus HMA,

Judging the results we see that WMA samples compared to HMA samples perform sometimes better and sometimes worse. It is known that the use of a zeolite for preparing small amounts of WMA in a lab will not always truly represent what happens during a larger drum mixing process (plant). It is plausible that more experience with the additive in combination with type of aggregate and type of filler and bitumen can make the difference. Therefore we decided to execute a couple of full scale test sections as reported about in the next paragraph.

4.2. Full scale test sections using PQ's zeolite advera

The advantages of using a zeolite made us eager to select a couple of pilot scale road works to do full scale testing; one at the asphalt plant of the NOAP at Heerenveen and the second one at the Hengelo asphalt plant of the ACH (both at the eastern part of the Netherlands). We started at the NOAP site by making a WMA mixture without RAP and adding the Advera manually. During the second step we used an automated dosage system and started to add 30% and 50% of RAP to the WMA mixture.

4.2.1. Lay out of the full scale pilot

We used the full scale test sections in order to address the following aspects:

- the performance of the asphalt mix both during paving and compacting,
- effects of the mixing process of the Advera into an existing production process,
- the combinations of making WMA and using RAP,
- The way the temperature of the total mix should be managed in order to get the right WMA production temperatures.

As mentioned before doing the full scale pilots we would test two aspects: making WMA using a zeolite and making WMA with (recycling material) RAP. To keep track on the effects of the different steps it is advisable to do this in a two-step procedure: a.) testing the WMA procedure using a zeolite without RAP, b.) as step 2, making WMA with RAP. As a result of both steps we evaluated the process and the product. At the second pilot sections we started with 30% RAP and added later on 50% of RAP.

Table 2. The lay out of the two full scale WMA test sections numbers 1 and 2.

Test section # 1, AC 16 Base no RAP Location Heerenveen (NL)	
Tons AC 16 Base	Ca. 120
# sections	3
Size of sections	720 m^2
RAP	0%
Dosage Advera	Manually using meltbags
Mixing temperature	130 ± 6 ˚C
Test section # 2, AC 16 Base & AC 22 Base 0%, 30% & 50% of RAP Location Hengelo (NL)	
Tons AC 16&22 Base	Ca. 665
# sections	6 x 2 (2 layers)
Size of sections	ca 2250 m^2
RAP	0%, 30% & 50%
Dosage Advera	Automated
Mixing temperature	134 ± 10 ˚C

For measuring the effect of the moment of dosage the Advera at the mixing drum we did a small tets procedure, added the Advera at different moment (related to the injection of the bitumen) and tested compactibility of the mix by deducing the voids percentage. The results are shown in table 3a. The different moments of dosage the Advera were;

- Procedure no. 1 dosage of the Advera 2 second before injecting the bitumen,
- Procedure no. 2 dosage of the Advera at the same moment of injecting the bitumen,
- Procedure no. 3 dosage of the Advera 5 second before injecting the bitumen.

Table 3a. The lay out of the two full scale WMA test sections numbers 1 and 2.

Density on cores WMA Advera dosage procedures 1-3, NOAP						
Dosage procedure #	1		2		3	
Core #	1	2	3	4	5	6
Density [kg/m^3]	2353	2380	2372	2376	2367	2334
Target density [kg/m^3]	2388	2388	2388	2388	2389	2389
Compaction grade [%]	98.5	99.7	99.3	99.5	99.2	99.7

The conclusion drawn from the figures of table 3a are that there is no significant different in arranged density, all cores are more or less compacted to the same level. From this procedure we draw the conclusion that dosage of the moment of the Advera to the mixture is not very critical. We continued further working with procedure no. 2, this implies dosing the Advera together with the bitumen.

During the first full scale pilot Advera test sections we studied the process of paving and compaction very carefully and measured during and afterwards results of interest. To study and monitor the process we measured the next parameters, see table 3:

Table 3. The measured data during the full scale WMA test sections.

Instrument	**Measure**
D-GPS (GPS with a local base station)	Movements of the paver and rollers
Manually (count)	Roller passes per location
Laserlinescanner	Surface temperature behind the screed
Thermo couples	Cooling in-asphalt temperature at a static point
IR camera	Cooling surface temperature at a static point
Troxler	Compaction grade after every roller pass at a static point
Weather station	Weather conditions during the process
Weighing density cores	Final compaction grade of paved layer

4.2.2. Full scale pilot: Control of temperature, compaction and workability

During the second full scale test, we monitored the paving and compaction process carefully. In table 4 is shown what variables we monitored and what instruments we used. The methodology to measure the process using these technologies is intensively reported by Miller (2010), Huerne et al (2006).

The weather conditions during paving were 6 °C, a wind speed of 0,5 m/s, fully clouded and once in a while a bit rain. Subsequently, we will shortly describe the results of these measurements.

Compaction was undertaken using two small 2.5 ton tandem rollers. Normally, they use a 10 ton tandem roller for the bulk compaction, but because the underground was a bit saturated, at this project they only used two small rollers.

From the GPS-data, we extracted a compaction contour plots that shows the number of roller passes that a certain roller conducted at a stretch of asphalt. An example of a stretch of 40m is shown in figure 3. This graph makes it visible that in the middle of the section ca. 6 more roller passes are conducted that at the beginning or the end of the stretch of asphalt. These graphs are made for the whole test section. From these results it became clear that there was a lot of variability in the number of roller passes that were conducted. The average number of roller passes applied at the whole test section is 8 roller passes with a standard deviation of 2,2 roller passes.

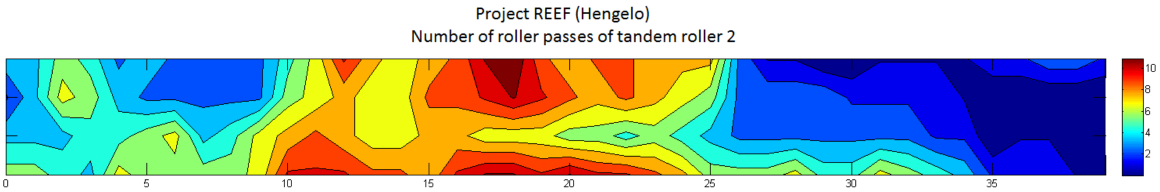


Figure 3. Distribution of roller passes of roller no. 2 on ACH full scale test section.

From the results of the laser linescanner we extract temperature contour plots that show the surface temperature behind the screed over the width of the road. The average temperature behind the screed was 110°C with a standard deviation of 20°C. So, also still a lot of variability is visible in the temperature behind the screed.

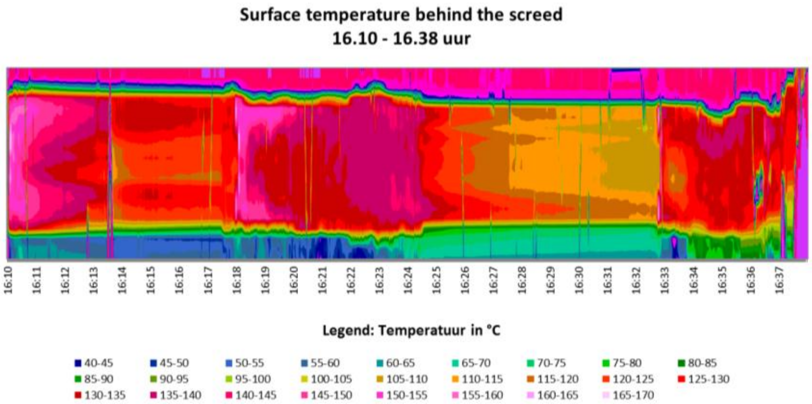


Figure 4. Measured asphalt mixture surface temperature directly after paving using IR linescanner equipment.

Additionally, we measured the cooling of both in-asphalt and surface temperature at some static points (about every 50m). At these points we also measured the density progression after every roller pass. In this way, it become possible to analyze the impact of a roller at a certain temperature. An example is shown in figure 5. In this example the density increases from about 2150 kg/m^3 and ends after 9 roller passes at 2430 kg/m^3.

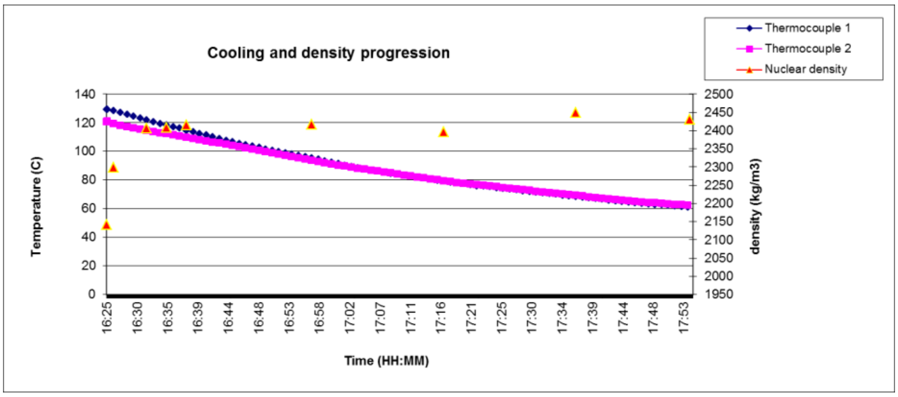


Figure 5. Cooling data of the in-asphalt temperature in combination with the progression in density by rolling measured by nuclear equipment.

From this second pilot study we conclude that there is still a lot of variability within the number of roller passes that are conducted and the temperature behind the screed. However, this is not different from the a normal HMA. Further on, more structures research should be conducted to test if the variability of WMA is more or less than at HMA.

4.3. Testing material properties from test sections.

From the second test section 60 cores and 54 slabs were extracted and tested in the laboratory. Tests were done in accordance to CROW 2010, test circumstances can be found in table 4.

Table 4. Test conditions and NEN-EN-norms of lab tests for WMA Advera slabs and samples.

Test conditions and NEN-EN-norms of lab tests		
	NEN-EN norm	Test temperature
Four point bending test	NEN-EN 12697-24 and 26	20˚C
Tri-axial testing	NEN-EN 12697-25	40˚C
ITS	NEN-EN 12697-12	15˚C

In table 5a and 5b the results of the mechanical tests are shown. From the results it became clear that WMA-Advera on both test parameters, with and without RAP, has a slightly higher density (0.5 and 1.3%), higher stiffness (0.84 and 2.2%), but unambiguous scores on fatigue (+5.4 and -6.1%) and also on rutting (+5.9% and -130%). The values on resistance against fatigue are for this asphalt mixture not directly critical but we want to investigate if we can identify a cause. The resistance against rutting is critical especial in samples with 50% RAP. We do not know what the exact cause is for this difference, further testing will focus on this phenomena.

Table 5a. Mechanical properties HMA and WMA-Advera (produced Heerenveen)

Parameter	**HMA-AC 16**	**WMA-Advera AC 16**
Density (kg/m^3)	2387	2398
Stiffness (E* in MPa)	7940	8007
Fatigue (ε_6 in µm/m)	115.6	122.2
Rutting (f_c in µm/m/pulse)	0.34	0.32

Table 5b. Mechanical properties HMA and WMA-Advera (produced Hengelo)

Parameter	**HMA-AC 22 50% RAP**	**WMA-Advera AC 22 50% RAP**
Density (kg/m^3)	2405	2437
Stiffness (E* in MPa)	9333	9544
Fatigue (ε_6 in µm/m)	126.0	118.3
Rutting (f_c in µm/m/pulse)	0.2	0.46

During paving the full scale test sections at Hengelo we did some tests to deduce the workability (voids %) of the WMA mixture at lower temperatures up to 70C. we did this by taking plant mixed material (WMA AC 16 Bind, 30% RAP) and campacted it at three different temperatures 120, 95 and 70˚C. We measured voids % after compaction and ITS values wet and dry. Results are shown in table 6.

Table 6. Results form Marshall compacted WMA test samples at different compaction temperatures.

Marshall compacted WMA test samples at different compaction temperatures		
Compaction at temperature…	Voids percentage [%]	ITSR [%]
120˚C	4.3	57

95˚C	6.0	79
70˚C	8.8	89

De following conclusions can be drawn from these results:

- Voids percentage is raising when compaction starts at lower temperatures, further testing must be done for deducing a more resize limit between 120 and 70˚C.
- ITSR tests show reasonable values until a compaction temperature of 95˚C.

5. IMPLICATIONS FOR THE PAVING INDUSTRY

The implications for paving practice of this study is that decision makers, like designers of the asphalt mixture or planners of the organisation of the project, must put more attention to the operational behaviour and performance regarding the resistance against rutting for this type of mixtures. For planners this means that the logistic is more critical to provide a continuous stream of asphalt for the paver. Also, project managers need to be aware that WMA is more vulnerable for loss of quality and therefore requires a more comprehensive preparation of the paving and compaction process. Additionally, road agencies should also be aware of this vulnerability to variability and this knowledge should be taken into account in the decision making process for applying WMA or HMA in a project.

6. FUTURE RESEARCH

Yet, we must acknowledge that still much is unknown and unclear about the consequences of producing asphalt mixtures at lower temperatures on the paving and compaction process. A number of relevant questions still cannot be answered, such as the effects of different compaction procedures or variability in key parameters on the quality of the WMA pavement. Therefore, we propose (and pursue) further research projects to further understand the relationships between compaction procedures and variability in key parameters on the final quality of WMA. These relationships can for example be simulated in the laboratory. From different studies became clear that rolling compaction in the laboratory has the most similarities with field compaction (De Visser et al, 2006; Renken, 2002). So, for future research rolling compaction equipment in the laboratory can be useful to determine the effects of different compaction strategies on the final quality of the WMA pavement.

Furthermore, the operational handling of WMA may be problematic for operators of the asphalt team. However the workability seems good from a performance perspective (it can reach the target density), it is recommended to conduct further research to decrease the physical intensity for the operators, for example through reducing the viscosity of the mixture or providing the operators with equipment that makes the operational handling of WMA easier.

7. CONCLUSION

The gathered and presented data show that WMA with Advera can perform similar to a standard HMA. The conducted lab experiments and field studies show good performance for the indirect tensile strength (kN), stiffness (E*), and resistance against fatigue (ε_6). However, the results for the resistance against rutting (f_c) show much variability: It can perform slightly better, but it can also perform much worse than a standard HMA. We plan to conduct further research to improve this property for this mixture. Possibilities to improve this parameter are increase the amount of stone, sand and filler in relation to the amount of bitumen, use a stronger filler or use more angular sand.

We also studied this WMA from a production point of view. At the asphalt plant we mixed the additive at various moments through the asphalt mixture. From these results, adding the additive in the production phase is good possible and seems not very vulnerable for a different moment of dosing the additive to the mixture. So, the process seems quite robust.

Furthermore, the gathered and presented data from the field studies show a lot of variability in operational behaviour, such as the initial surface temperature during lay-down and compaction procedures. However, these variability's are not specifically for WMA, but seems more the consequence of an uncoordinated approach. Nevertheless, WMA seems more vulnerable for this variability in operational behaviour than HMA, especially for the resistance against rutting and therefore give the impression to be more critical for the final quality of the asphalt pavement. This vulnerability makes intensive monitoring and quality control more important. Technologies like a laserlinescanners, infraredcameras and thermocouples can be useful to monitor the temperature during the process and GPS-equipment is applicable to monitor the movements of machinery and analyse working methods of the asphalt team.

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