LOW TEMPERATURE ASPHALT (WMA) IN SWEDEN

Submission date: 31 August 2011

Word count: 3 742

Corresponding author:
Nils Ulmgren, MSc, Development Manager, NCC Roads AB
Address: SE-170 80 Solna, Sweden. Phone no: +46 706403564. E-mail: nils.ulmgren@ncc.se.

Co-authors:
Roger Lundberg, Technical Manager, NCC Roads Sweden North
Address: Box 455, SE-90 109 Umeå, Sweden. Phone no: +46 705882206. E-mail: roger.lundberg@ncc.se.

Lorentz Lundqvist, Product Manager, NCC Roads AB
Address: Brogatan 33, SE-931 62 Skellefteå, Sweden. Phone no: +46 706244486. E-mail: lorentz.lundqvist@ncc.se.
ABSTRACT

In Sweden, the definition for Hot-mix asphalt (HMA) is that the production temperature should at least be 120°C (248°F), but it is usually produced at 150-160°C (302-320°F). The same definition is used for Warm Mix Asphalt (WMA), in Sweden called Low temperature asphalt, and subsequently that the quality compared to HMA should be the same in every aspect.

In 2010, the first big project with WMA was started after several years of minor trials with different techniques. Among these techniques might especially be mentioned the use of different additives and developed new processing techniques. The project in question is the paving of a new interstate highway with two lanes in each direction with a total length of 24.5 km (15.2 miles) in the northern part of Sweden at Hudiksvall 350 km (217 miles) north of Stockholm (compares to 100 km (62 miles) north of Anchorage, Alaska). The contractor for the asphalt works is NCC Roads AB and the technique used for the production of the WMA is based on foam-technique without any special additives, besides amine as an adhesion agent. Before the production and paving started a thorough laboratory study was performed to establish the optimal composition of the asphalt. The laboratory analyses include besides normal testing determination of parameters such as resistance to deformation, stiffness, water sensitivity, resistance to abrasion against studded tires and workability. On site, first a test trial of 1000 m (1094 yards) was performed together with a reference section of 3000 m (3281 yards). The same laboratory tests as in the pre-study have been performed on samples from the test section as well as the reference section. The results from the analyses from the pre-trials show that the quality is as good for the WMA as the normal HMA.

During 2010 and 2011 about 120 000 tons of WMA are now produced and paved on 19 km in three layers of base, binder and wearing course evenly distributed between the two years. The production quality is verified by the same regime of testing as in the pre-testing.

The paper presents experiences from the production but focus on the quality aspects as shown from the testing of samples from mix and pavement. So far the results show that the WMA is as good as the HMA but special attention should be paid to the moisture content, which is somewhat higher (0.15 % compared to 0.05 %) and its influence on the water sensitivity. It makes it vital to add an adhesion agent.

Results from laboratory analyses of samples from the pavement are included as of mid August 2011.
INTRODUCTION

Low temperature asphalt (WMA) as we know it today was in Sweden first produced some ten years ago and since then several techniques for this purpose have been introduced, which includes both process techniques such as foamed bitumen and methods that include addition of different additives. In Sweden so called half-warm mixes with production temperatures of 50-100°C (122-212°F) are quite common and subsequently Hot-mix asphalt (HMA) with normal production temperatures of 150-160°C (302-320°F) in Sweden has been defined as mixes for which the production temperature is at least 120°C (248°F). There have been some discussions about how to define WMA and today there is an agreed definition. It makes a clear distinction between processes with a production temperature above 100°C (212°F) and processes below 100°C (212°F), i.e. the difference between “dry” and “wet” mixes. The definition for Low temperature Asphalt (WAM) is now that the production temperature shall be over 120°C (248°F) and with the same quality criteria in all aspects as for ordinary Hot mix asphalt. The reason for 120°C (248°F) and not 100°C (212°F) is that it is in practice almost impossible to dry the aggregate at a temperature below 120°C (248°F).

In Sweden the production and experience of WMA has been so successful that the Road Administration has now accepted to use it in a larger scale. In 2010 the first big project with WMA was started with the understanding that it should be used to prove that this is a technique for the future. The project in question is the paving of a new interstate highway with two lanes in each direction with a total length of 24.5 km (15.2 miles) in the northern part of Sweden at Hudiksvall 350 km (217 miles) north of Stockholm (compares to 100 km (62 miles) north of Anchorage, Alaska). Estimated daily traffic is 7 500 YDTTotal and 1 700 YDTHeavy (Heavy vehicle is >3.5 tons) with an estimated increase of 1.6 %/year. The frequency of studded tyres is 65 %. The contractor for the asphalt works is NCC Roads AB. The technique used for the production of the WMA is based on foam-technique without any special additives, besides amine as an adhesion agent. Of the total of 24.5 km (15.2 miles), 3 km (1.86 mile) will be set aside as a reference of ordinary produced HMA.

The paper describes some of the pre-work in laboratory and pre-trials that have been performed in 2009 and early 2010, but is focused on the season of 2010 and the first half of 2011 when about 3/4 of the total asphalt of 120 000 tons on the site has been produced. An extensive control has been performed with the aim to study the achieved quality. The environmental factors such as energy savings and carbon footprint have not been studied. The rest of the 120 000 tons will be produced during the second half of 2011.

PAVEMENT DESIGN

The pavement (slow moving lane) consists of three bound layers of base 86 mm (3.39 in) AC 32 (1.26 in), binder 50 mm (1.97 in) AC 16 (0.63 in) and wearing course 35 mm (1.38 in) SMA 11 (0.63 in) on two unbound layers of crushed rock material consisting of base 80 mm (3.15 in) 0-32 mm (0-1.26 in) and sub base 600 mm (23.6 in) 0-100 mm (0-3.94 in) respectively. The thicknesses of the unbound layers are dependant of the frost depth in the geographic area. In the fast moving lane, there are only two asphalt layers, wearing course 35 mm (1.38 in) SMA 11 and base course 45 mm (1.77 in) AC22.

The bitumen is of standard quality penetration 100/150 for wearing and binder course and 160/220 for base course as it is a northern geographic area. All asphalt mixes contain RAP: 5% in wearing course, 20 % in binder course and 30% in base course. A limitation for the use of RAP is foremost the possibility to uphold the composition in accordance with the tolerances of the recipe. The aggregate for binder and base courses are taken on site, but as there are special quality requirements for resistance against abrasion for the wearing course this material is hauled from elsewhere. The same goes for the RAP for this layer.

In all the asphalt production will consist of 141 000 tons distributed as follows

- Wearing course 36 000 tons
- Binder course 29 000 tons
- Base course 76 000 tons
Whereof 124 000 tons will be WMA and 17 000 tons HMA. 1000 m (1094 yards) are set aside for special WMA trials, including plans for higher amount of RAP and the use of polymer-modified binder, during the season 2011.

**RAP**

The basic idea with WMA is to produce at a lower temperature than normal. When producing a normal HMA the production temperature will be above 150°C (302°F) for two reasons: a) to have a viscosity of the binder that makes it soft enough to cover the aggregate easily and b) to dry the aggregate so no moisture is left. If the aggregate is heated to no more than 120-130°C (248-266°F) there is no really guarantee that all moisture has been removed, which makes this one important challenge for the WMA technique.

To be able to dry the aggregate at a temperature over 150°C (302°F) unheated RAP might be added at such a proportion that the mixed components end up with a temperature of 120-130°C (248-266°F). Adding RAP can then be seen as an important issue for producing WMA where the aggregate has been fully dried. However, of course, the RAP in itself contains some moisture, it is important to keep this as low as possible and it should not be over 2%. Even so there will be some moisture left of a magnitude of about 0.1%, but experience so far shows that this can be handled by adding a little more of an adhesion agent than normally.

Covering of the stockpile of RAP is today used at several plants, as this will guarantee that the moisture content is kept at a low level and this is strongly recommended.

**LABORATORY WORK**

Before the production and paving started a thorough laboratory study was performed to establish the optimal composition of the asphalt.

Before blending, the RAP was analyzed for bitumen content, sieve curve, penetration, softening point and moisture content. The hardness of the RAP is about 60 expressed with R&B value.

The laboratory analyses included normal testing on blended mixes (binder content, sieving curves) and also penetration and softening points of the binders before and after blending and moisture left in the mixtures after blending. Marshall compacted samples were analyzed for void content. An important parameter has been the workability of the mix. Samples have been produced in laboratory for testing of mechanical characteristics such as resistance to deformation, stiffness, water sensitivity and resistance to abrasion against studded tires. The tests are performed according to the new European Standards (see table 1). The results from these laboratory tests are not presented here partly because of lack of space but also because of most of the same tests have been used for testing on site and as these results are of greater interest they are presented below (see table 2).

**TABLE 1 Testing for mechanical characteristics on cores, parameters and methods used**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistance to deformation</td>
<td>EN12697-25 part A Uniaxial compression test with confinement (2)</td>
</tr>
<tr>
<td>Stiffness</td>
<td>EN12697-26 part C Indirect tensile test (IT-CY) (3)</td>
</tr>
<tr>
<td>Water sensitivity</td>
<td>EN12697-12 Indirect tensile strength ratio (4)</td>
</tr>
<tr>
<td>Resistance to abrasion</td>
<td>EN12697-16 part A Abrasion by studded tyres - Prall (5)</td>
</tr>
</tbody>
</table>

As mentioned above a key factor for a good quality of the end product is to have control over the moisture content of this type of mix, so there has been a special focus on this during the laboratory work (see also Production below). Different types and amount of adhesion have been tested and AD-here® LOF 65-00 was selected besides good quality also for low smell potential.

The workability of the mixes was tested with two test methods: the workability test and compaction ability using a gyratory machine. The workability test (6) has been developed mainly for cold mixes, but can be used in this context as an indicator, i.e. this test, as well as the gyratory machine, cannot
be used to get exact figures but rather to show tendencies and they are helpful tools to be able to distinguish between the good and the bad mixes.

Recipes for the different mixes were selected from these studies and these recipes were then used in the pre-trials (and then in the main production with only minor adjustments) discussed below. The mixtures, which are all standard mixes, are

- SMA 11 surf 100/150 6.6% = Stone Mastic Asphalt with maximum aggregate size 11 mm for wearing course with 6.6 % penetration bitumen 100/150
- AC 16 bin 100/150 5.2% = Asphalt Concrete with maximum aggregate size 16 mm for binder course with 5.2 % penetration bitumen 100/150
- AC 22 base 160/220 4.5% = Asphalt Concrete with maximum aggregate size 22 mm for base course with 4.5 % penetration bitumen 160/220
- AC 32 base 160/220 4.0% = Asphalt Concrete with maximum aggregate size 32 mm for base course with 4.0 % penetration bitumen 160/220.

**PRODUCTION UNITS**
The following production units are being utilized:

- Asphalt plant: Astec Double Barrel from 1994 refurbished for production of Low temperature asphalt (WMA) (see figure 1). The process is based on foam-technique but also other important changes in the production process concerning where and when the different components are added. To make the mix less sensitive to water a fluid adhesion agent is added. (The same principal technique as described is used in batch-plants at other sites.)
- Paver: Dynapac F161-8W
- Shuttle-buggy: Roadtec SB25000 (see figure 2)
- Compactors: Hamm HD140 and Dynapac CS142.

![Asphalt plant, an Astec Double Barrel from 1994, refurbished for production of Low temperature asphalt.](image)

**FIGURE 1** Asphalt plant, an Astec Double Barrel from 1994, refurbished for production of Low temperature asphalt.

**PRE-TRIAL AND PRODUCTION RESULTS**
A pre-trial was performed on site in May 2010 consisting of a test section of 1000 m (1094 yards) of WMA with recipes from the laboratory studies. In connection with this, the reference section of 3000 m (3281 yards) with the same recipes but produced as ordinary HMA were paved. From both sections a lot
of cores have been taking for testing of, besides void content, also mechanical characteristics with the same laboratory tests (except stiffness) as in the pre-study.

The results from the analyses from the pre-trials showed that the quality was at least as good for the WMA as the normal hot-mix, which gave us the courage to go on with the full size production. In the following tables (table 2-5) are shown the results from analyses on samples from the road. The results for the WMA pavement include the pre-trial as well the full production during 2010. Results are included as of mid August 2011, which represents a little more than 2/3 of the total production.

**FIGURE 2 Shuttle-Buggy for homogeneity.**

**TABLE 2 Comparison of results from laboratory analyses on samples (cores) from site between WMA and HMA for SMA 11 surf**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>No of samples</th>
<th>HMA Reference</th>
<th>WMA</th>
<th>Normal requirements Wearing course</th>
</tr>
</thead>
<tbody>
<tr>
<td>Void content</td>
<td>%</td>
<td>10</td>
<td>2,4±0,7</td>
<td>43</td>
<td>3,2±1,3</td>
</tr>
<tr>
<td>Change in softening point</td>
<td>°C</td>
<td>1</td>
<td>1,8</td>
<td>3</td>
<td>2,6±0,5</td>
</tr>
<tr>
<td>Water sensitivity</td>
<td>ITSR %</td>
<td>-</td>
<td></td>
<td>3</td>
<td>79±6,0</td>
</tr>
<tr>
<td>Resistance to abrasion</td>
<td>Cm^3</td>
<td>4</td>
<td>32±3</td>
<td>10</td>
<td>31±2,4</td>
</tr>
</tbody>
</table>
### TABLE 3 Comparison of results from laboratory analyses on samples (cores) from site between WMA and HMA for AC 16 bin

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>No of samples</th>
<th>Average result and standard deviation</th>
<th>No of samples</th>
<th>Average result and standard deviation</th>
<th>Normal requirements Binder course</th>
</tr>
</thead>
<tbody>
<tr>
<td>Void content</td>
<td>%</td>
<td>5</td>
<td>3,9±1,5</td>
<td>45</td>
<td>4,5±1,2</td>
<td>3,0-8,0</td>
</tr>
<tr>
<td>Change in softening point</td>
<td>°C</td>
<td>-</td>
<td>4</td>
<td>4</td>
<td>5,8±1,0</td>
<td>≤ 6</td>
</tr>
<tr>
<td>Resistance to deformation</td>
<td>Micro strain</td>
<td>1</td>
<td>12 600</td>
<td>3</td>
<td>17 930 ±2 180</td>
<td>≤ 21 000</td>
</tr>
<tr>
<td>Water sensitivity</td>
<td>ITSR %</td>
<td>1</td>
<td>75</td>
<td>2</td>
<td>72±2,1</td>
<td>≥ 75</td>
</tr>
</tbody>
</table>

### TABLE 4 Comparison of results from laboratory analyses on samples (cores) from site between WMA and HMA for AC 32 base

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>No of samples</th>
<th>Average result and standard deviation</th>
<th>No of samples</th>
<th>Average result and standard deviation</th>
<th>Normal requirements Base course</th>
</tr>
</thead>
<tbody>
<tr>
<td>Void content</td>
<td>%</td>
<td>7</td>
<td>4,0±1,2</td>
<td>40</td>
<td>4,1±1,0</td>
<td>3,0-8,0</td>
</tr>
<tr>
<td>Change in softening point</td>
<td>°C</td>
<td>1</td>
<td>8,8</td>
<td>3</td>
<td>8,5±0,5</td>
<td>≤ 6</td>
</tr>
<tr>
<td>Water sensitivity</td>
<td>ITSR %</td>
<td>2</td>
<td>77±1,2</td>
<td>5</td>
<td>68±12,0</td>
<td>≥ 60</td>
</tr>
</tbody>
</table>

### TABLE 5 Comparison of results from laboratory analyses on samples (cores) from site between WMA and HMA for AC 22 base

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>No of samples</th>
<th>Average result and standard deviation</th>
<th>No of samples</th>
<th>Average result and standard deviation</th>
<th>Normal requirements Base course</th>
</tr>
</thead>
<tbody>
<tr>
<td>Void content</td>
<td>%</td>
<td>5</td>
<td>4,4±0,9</td>
<td>33</td>
<td>5,2±1,3</td>
<td>3,0-8,0</td>
</tr>
<tr>
<td>Change in softening point</td>
<td>°C</td>
<td>1</td>
<td>9,2</td>
<td>3</td>
<td>7,9±1,2</td>
<td>≤ 6</td>
</tr>
<tr>
<td>Water sensitivity</td>
<td>ITSR %</td>
<td>1</td>
<td>77</td>
<td>2</td>
<td>74</td>
<td>≥ 60</td>
</tr>
</tbody>
</table>

### Explanations to the tables
- Normal requirements for this type of road with 1700 daily heavy traffic (> 3.5 tons).
- Requirements for change in softening point are valid without RAP.
- Resistance to abrasion: One test consists of the average of four specimens.
• Resistance to deformation: One test consists of the average of five specimens.
• Water sensitivity: One test consists of the ratio between the average of five wet conditioned specimens (after saturation storage for 7 days in water of 40°C) and five dry conditioned specimens.

The results are discussed below.

QUALITY OF PRODUCED ASPHALT
During production, several lines of control have been set up as follows:
• Control of temperature at asphalt plant and at site
• Production control at the asphalt plant including extraction of mix samples for control of composition and compaction characteristics (Marshall compaction)
• Control of moisture content
• Control of homogeneity by Linear scanning
• The asphalt pavement is then verified by the same regime of testing as in the pre-testing

Control of temperature at asphalt plant
Producing WMA means that the production temperature should be between 120-130°C (248-266°F) compared with HMA where the production temperature normally is 150-160°C (302-320°F) (depending on the bitumen penetration). The production temperature has been continuously monitored and show results in accordance within the stipulated limits above. The temperature of the mix is also controlled by the Linear scanner (see below).

Production control at the asphalt plant
The standard production control of composition shows only normal variations and no difference between WMA and HMA.

Control of moisture content in ready mixture
The moisture content has been tested continuously on mix samples from the WMA as well as the HMA production and the set up requirement of < 0.15% have been met on all samples, with one or two exceptions at 0.16%. The moisture content of the HMA is normally below 0.05%, so there is a small disparity between the production techniques, but at same time, there are no distinctions between the various mixes regardless of differences in RAP content.

Control of pavement homogeneity by Linear scanning
The linear scanner (not be confused with an ordinary video camera) is an advanced temperature scanner that has been used in Sweden for almost 15 years. It has been presented at a congress in Barcelona 2000 (1). The equipment is used to control the tendency of separation/segregation of the mix/pavement by measuring the variation of the surface temperature. An example of achieved homogeneity is shown in figure 3. To evaluate the results so called “Risk areas” are defined. They stand for areas where the temperature is lower than 10% of the measured average. A Risk factor (expressed in area) of less than 2.5% is considered as very good. In this case, with the WMA the values are extremely good with figures very close to zero with an average for all areas of 0.19%.
The Linear scanner gives normal paving temperatures at 110-120°C (230-248°F) for the WMA and 140-150°C (284-302°F) for HMA.

Testing of asphalt pavement and discussion of the results
The control program from the pre-trials has been copied for use on the main length of the road pavement; so many cores have been taken for testing of besides void content also mechanical characteristics with the tests listed in table 1. The results are presented in tables 2 to 4 above.

The results show that the quality of WMA is comparable to the ordinary HMA, and fulfill standard requirements, but also that there may be some areas which have to be focused on, i.e. some risk parameters for WMA. The most important factor seems to be the water sensitivity, as there is a clear tendency in the results that the ITSR are somewhat lower than for the HMA, even if they normally are inside tolerance limits.

Analyses of the change in softening point show no difference between WMA and HMA, which is perhaps somewhat surprising, as it would be believed that a lower production temperature should lead to less hardening of the binder. That we see no difference in this case might be an effect of this special asphalt plant and its mixing principle, as we see a more clear difference when using batch-plants. The results are in most cases outside given tolerances, but that is because the tolerances do not give account for the content of RAP and its harder binder in the mixes. Calculations shows that the RAP (R&B about 60°C (140°F) content counts for an increase of about 6.6°C (11.9°F) in the AC32 base (30% RAP) and for about 2.8°C (3.6°F) in the AC16 bin (20% RAP). This means that the increase due to the production is limited to about 2-3°C (3.6-5.4°F), and it is the same for both WMA and HMA.

Experiences from production and paving
There is very little difference to work with WMA compared to ordinary HMA. One might say that the differences are mostly positive mainly from the workers point of view considering the much more pleasant atmosphere at the working place. One other point might be worth mentioning and i.e. because of the lower
temperature in all for the WMA it takes longer time to get the equipment up to working temperature, which should be taken into account when starting up the work on cold mornings.

YEARLY MEASUREMENTS
For the upcoming five years the road pavement besides ocular inspections will be measured each year in respect to

- Rut depth
- Evenness (International Roughness Index, IRI)
- Cross fall
- Loss of fine material/mastic
- Characteristics of the binder
- Water sensitivity (ITSR for cores)
- Texture (Mean Profile Depth, MPD)

REFERENCES