Warm Mix Asphalt in Germany, a technology beyond reduced mixing and paving temperatures

Abstract

Warm Mix applications started in Germany in the 1990’s. In the federal state of Hamburg first trials were conducted in 1998 with Fischer-Tropsch Wax with paving temperatures between 130°C and 140 °C (270-285 °F). In 2004 after years of trials with many different technologies the Bundesanstalt für das Straßenwesen (Federal Road Authority, BAST) had mandated a large scale comparative trial on Autobahn BAB A7 near the city of Flensburg. This site has a traffic load of approx. 10,500 10-t-Axles / day. Before and after paving the trial sections extensive comparative analyses were performed on the bitumen. The asphalt mixes properties were inspected for compaction, deformation resistance in high temperatures and cold temperature performance. The positive results from this trial coupled with the analysis of cores taken from pavements older than 5 years (duration of guarantee) lead to the listing of two additives for lowering asphalt temperature by BAST: Mineral additives and viscosity-altering organic additives. Since 2004 these technologies have firmly established themselves, especially after frequent testing and monitoring of projects from the 1990’s, delivering proof that these warm mix asphalt constructions are at minimum equal to hot mix asphalt. There is a strong indication that warm mix asphalts are ageing slower due to lower thermal degradation during manufacturing and paving. Also higher degrees of compaction can be reached, eliminating one of the dominant failure modes for asphalt pavements. Initial fears that the significant stiffening of binder caused by organic additives would substantially shorten the life of pavement and cause low temperature failures have not manifested themselves anywhere. Binder testing according to PG grading would have strongly suggested such failures. Over more than 10 years and many millions of tons paved there is no indication of any negative impact on the low temperature performance. These positive findings as well as practical experiences gained with extremely stiff binders for mastic asphalt have encouraged the use of organic additives beyond temperature reduction. Increasingly binders modified with these additives are used to refine SMA formulations for even better compaction and performance. High modulus construction of highway-, airport- and container terminal pavements are firmly established. Newer applications are ground tire rubber...
binders, thin layer friction courses, high quality mixes with more than 30 % RAP to name a few. In these applications quality aspects pay for the additives. Energy savings, reduced emissions and lower exposures of workers to fumes and emissions come as a very desirable side benefit.

1. Introduction

1997 the author was contracted by the Baubehörde Hamburg (DOT of Federal state Hamburg, Germany) to investigate new methods to minimize rutting of asphalt roads. Alongside the optimisation of grading curves a focus was set on modification of binders. By that time polymer modified binders were established with good effects against deformations under hot temperatures. However, these modifications require a higher compaction effort to reach the required density which under adverse conditions is problematic.

For this reason it was decided to investigate binder modification with modifiers that increase deformation resistance but do not introduce higher binder viscosity or even reduce it. A promising product was Fischer-Tropsch (FT) Paraffin. It fully melts at temperatures above 105 °C (221 °F) and liquifies the binder in mixes above this temperature. This Technology can also be used to reduce the mix temperatures. After extensive laboratory research on binder and mixes modified with FT Paraffin a test site was chosen and paved. It is situated on a street named Veddeler Damm in the port of Hamburg in a location with a very high frequency of heavy axle loads where after 5 years under this traffic the deformation stayed below 5mm. 14 years after paving the test site still exists and performs well even under traffic that has strongly increased since time of construction.

In the meantime the discussion about the exposure of asphalt workers to fumes and aerosols from bitumen and asphalt mixes emerged. Very quickly the reduction of temperatures during mixing and paving of hot mix asphalt became a strong focus of research. The positive results of the Veddeler Damm site encouraged BAST (German equivalent to FHWA) to build a large trial site on Autobahn no.7 (BAB A7) where different technologies for temperature reduction were used and compared.

2. Testroad BAB A7

This site is located in the North of Germany near Flensburg. The lanes leading from north to south is exposed to approx. 2,500 heavy trucks per day. On seven sections with a length of 850 m each an 8 cm thick binder course and a 4 cm wearing course were designed and paved with binders containing either FT-Paraffin or Amide Waxes. Shortly after a second location was found in eastern Germany for evaluation of additives based on Montan Wax or Zeolithes. For this paper the author is solely focusing on the BAB A7 trial. Defined target was to pave and reach compaction at temperatures below 145 °C (293 °F) which is equivalent to at least 20 °C below the standard paving and compaction temperatures of equivalent binders. For this project polymer modified binder PMB Pen 45 was used for the control. The other sections used straight PEN binders modified with the different technologies as well as PMB modified with waxes.

All sections were paved and compacted at temperatures between 130-135 °C (275 °F). All sections except one variation with PMB reached compaction. The compaction problems were later traced back to roller regime and a deviation in grading curve against
mix design. The test site was built under an extended 8 year warranty (normal warranty is 5 years). The site is visually inspected every year. So far there are no observations on record where the test sections differ from control or other Autobahn sections of similar design and age. Coring after 5 years produced no negative observations. In below tables the results of that inspection are listed for the combinations of straight run bitumen with the waxes vs. the control—.
The Binder analysis shows that the wax modified binders do not display meaningful hardening, actually their softening points are slightly lower after 5 years. All binders also display good deep-cold temperature behaviour according to BBR. There is no technical explanation to the fact, that the softening point or the G* value of the binder course decrease. One reason may be that two different laboratories made the binder tests. The next evaluation will be in 2012. The momentary behaviour of all surface courses with waxes is very good: no cracking, no fretting and no rutting.

Although the paving temperature for the sections described in the above tables were approx. 30 °C (86 °F) lower compared to the control the void content are practically the same at same compaction effort (the trial setup contained identical roller regimes per section).

Emissions of fumes and aerosols were measured at the paver. As could be expected, the sections with reduced paving temperatures emitted far less than the control. Figure 1 displays the measured results. The temperature reduction clearly reduces exposure of workers to fumes and aerosols from bitumen.

### Table 1: binder characteristics of binder course AC 16

<table>
<thead>
<tr>
<th></th>
<th>FT-wax</th>
<th>Amide wax</th>
<th>PmB Pen 45</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air void content of compacted layer [vol.-%]</td>
<td>5,9</td>
<td>4,9</td>
<td>5,5</td>
</tr>
<tr>
<td>year</td>
<td>2004</td>
<td>2008</td>
<td>2004</td>
</tr>
<tr>
<td>Softening point [°C]</td>
<td>86,4</td>
<td>77,4</td>
<td>100,1</td>
</tr>
<tr>
<td>Penetration [1/10 mm]</td>
<td>26</td>
<td>18</td>
<td>29</td>
</tr>
<tr>
<td>G* (\delta 60°C) [Pa]</td>
<td>29100</td>
<td>21398</td>
<td>24100</td>
</tr>
<tr>
<td>(\delta 60°C) [°]</td>
<td>66,9</td>
<td>69,5</td>
<td>76</td>
</tr>
<tr>
<td>Stiffness – 16°C [MPa]</td>
<td>182</td>
<td>188</td>
<td>283</td>
</tr>
<tr>
<td>m- value</td>
<td>0,31</td>
<td>0,31</td>
<td>0,30</td>
</tr>
</tbody>
</table>

### Table 2: binder characteristics of surface course SMA 11

<table>
<thead>
<tr>
<th></th>
<th>FT-wax</th>
<th>Amide wax</th>
<th>PmB Pen 45</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air void content of compacted layer [vol.-%]</td>
<td>4,2</td>
<td>4,7</td>
<td>6,2</td>
</tr>
<tr>
<td>year</td>
<td>2004</td>
<td>2008</td>
<td>2004</td>
</tr>
<tr>
<td>Softening point [°C]</td>
<td>84,4</td>
<td>78</td>
<td>104,3</td>
</tr>
<tr>
<td>Penetration [1/10 mm]</td>
<td>30</td>
<td>16</td>
<td>33</td>
</tr>
<tr>
<td>G* (\delta 60°C) [Pa]</td>
<td>18300</td>
<td>22816</td>
<td>25400</td>
</tr>
<tr>
<td>(\delta 60°C) [°]</td>
<td>73,8</td>
<td>73,3</td>
<td>68,5</td>
</tr>
<tr>
<td>Stiffness – 16°C [MPa]</td>
<td>212</td>
<td>252</td>
<td>182</td>
</tr>
<tr>
<td>m- value</td>
<td>0,38</td>
<td>0,29</td>
<td>0,32</td>
</tr>
</tbody>
</table>
One might argue that the emission levels found on the trial site for the control section are already very low and do reflect a level that is deemed uncritical. The point is that the use of warm asphalt technology was able to significantly reduce even this low emission level. A look at the weather data for that day reveals that wind was blowing with approx. 5-6 m/s (10-13 knots) which “diluted” the fumes and aerosols. Figure 2 displays other data that was produced at the time of the trial by the German workers protection agency (Berufsgenossenschaft). This data confirms the trend that was found on the BAB A7 test site.

Due to the reduced mixing temperature from 160 /170 °C down to 145 °C about 10% energy could be saved. To achieve a very good coating of the chippings a longer wet mixing period of 10 sec was necessary, which reduced the production capacity by about 25%.
3. Properties of binders and asphalt mixes manufactured with viscosity reducing additives

Today, 14 years after first studies were started, the market is using viscosity reduced systems, mainly FT-Paraffin and Amide wax. Exemplary for these products Butz [1] investigated the influence of FT-wax on different road bitumens by blending with 3 % and 4 %. He found out, that “contrary to general belief paraffins do not have an entirely negative effect on bitumen quality”. The origin of the bitumen has practically no influence. Homogeneous blends of road bitumen and FT-wax have a very good hot storage stability at 160 °C (320 °F).

The needle penetration is lowered by 1 to 2 classes (PEN grades). The softening point is markedly increased by 35-40 °C (95-104 °F).

The following figures are based on fundamental investigations of the author, executed in 1998 till 2001.

As figure 3 and 4 show, the modification with FT-wax leads to a reduction in the phase angle $\delta$ and an increase in the storage modulus $G'$. This indicates a more elastic and stiffer behaviour, the resistance against rutting is remarkable improved.

![Figure 3: Phase angle of road bitumen and with 3 % FT-wax modified](image)

**Rolled Asphalt**

- conventional asphalt: 160 - 180°C
- low temperature asphalt: approx. 130°C

**Paver operator**

- 6,5 mg/m$^3$
- 0,4 - 3,1 mg/m$^3$

**Screed operator**

- 10,4 mg/m$^3$
- 0,6 - 6,9 mg/m$^3$
Figure 4: Storage modulus $G'$ of road bitumen and with 3 % FT-wax modified road bitumen Pen 80

Edwards [2] studied the effects of commercial waxes on asphalt concrete mixture performance at low and medium temperatures by using Tensile Stress Restrained Specimen Test (TSRST). The TSRST fracture temperature of non-waxy bitumen was somewhat increased (from -34 to -32 °C) from the addition of 6 % FT- wax, which is an abnormal high content. Ageing (42 days at 85 °C) made the TSRST fracture temperature increase by 1 to 5 °C. The addition of 6 % FT wax is rather of academic interest for investigating extremes as the usual application level covers the range of 1.5-3 %. With 3 % FT wax the increase of the TSRST was for different asphalt mixes between 0 and 1.6 °C [3]. The author [3] investigated in detail the influence of different contents of FT- wax between 0 % and 4.5 %. Figure 5 shows the change of dynamic viscosity at high temperatures.
Modification of bitumen with wax leads to a significantly lower viscosity. The ideal viscosity for asphalt mixing is reached at a 20 °C [71 °F] lower temperature. Experience in the field over the last decade has shown that the effective potential for temperature reduction is larger – up to 35°C [°F] because FT-wax not only introduces a viscosity reducing effect but also introduces lubrication into the mix. [4]

Figure 6 shows the deep temperature behaviour, investigated with the fracture breaking point Frass. With this test method a thin bitumen film on a metal plate is deflected, the test is repeated by decreasing temperatures with steps of 1°C (33.8 °F) till the first crack appears. The deep temperature behaviour is practically not influenced by the FT-wax content up to 4 % as shown by figure 5. The variation of the measurement readings was in this example within the repeatability limits of the test method. A higher content of the
additive may increase the breaking temperature but this addition rate lies beyond economically sensible borders. In practise we limit the wax content to max. 3%.

Figure 6: Influence of the FT-wax content on the fracture temperature 

The deep temperature behaviour is practically not influenced by the FT-wax content up to 4% as shown by figure 5. The variation of the measurement readings was in this example within the repeatability limits of the test method. A higher content of the additive may increase the breaking temperature but this addition rate lies beyond economically sensible borders.

Figure 7 shows the considerable increase of the resistance against rutting by addition of 3% FT-wax, investigated with the Hamburg Wheel Tracking Tester. A steel wheel passes 20,000 times an asphalt plate of 4-8 cm thickness at a temperature of 50 °C (122 °F), the
rut depth is measured.

Figure 7: Resistance against rutting with and without FT-wax

The limiting value for the wheel tracking test is 3.5 mm, because it is known by experience in Hamburg that even highways with very heavy duty – more than 15,000 10-t-axel load/ per day – have not rutting higher than 10mm after 10 years.

4 Specifications for warm mix asphalt
Based on the results of the test road highway BAB A7 the German highway authority BAST recommend the use of warm mixed asphalt. 2006 a guideline on temperature reduced asphalt mixes was published by FGSV-Forschungsgesellschaft für Straßen- und Verkehrswesen, the body that governs national specifications in Germany [5]. The listed organic additives are Fischer-Tropsch wax, Montan waxes, Amides of fatty acids and a mineral based additive, Zeolithe. Zeolithes contain crystal water that is released during the asphalt mixing process and approx. 4 hours after mixing.

BAST [6] has published a list which by now contains 10 additives or ready made binders that have passed proof of performance. Momentarily FT-wax (Sasobit) is the product most used by the industry in Germany.

A peculiar asphalt mix has been further regulated. Mastic asphalt that used to be manufactured and paved at temperatures between 240 and 270 °C is now regulated to a maximum temperature of 230 °C (446 °F) [7]. Exposures of workers to fumes and aerosols for this kind of mix had far surpassed threshold levels. Without sacrificing deformation resistance this is not possible without use of viscosity reducing additives. A further lowering of temperatures to 200 °C (392 °F) is envisaged. A combination of FT-wax and Zeolithe has already been tried at temperatures of 180 °C (356 °F). Mastic asphalt is in Germany a key technology e.g. for the waterproofing of bridge decks and other elevated structures such as parking garages.

5 Preferred preferred applications of viscosity reduced binders
The asphalt industry in Germany does not use viscosity reduced systems or “warm asphalt” primarily for temperature reduction of mixes. Especially the waxes are employed
for enhancing deformation resistance and/or for improved workability.

Main fields of application are:
- airports and container terminals: against rutting and plastic deformation
- urban roads: longer compaction time
- bridge deck waterproofing and asphalt layers: mastic asphalt
- thin and ultra thin wearing courses: better compactibility
- cold weather conditions: compaction even at temperatures around freezing
- early traffic release due to earlier curing

6 Remarks about foamed asphalt
Foamed asphalt does not play any role in Germany. Tests with foamed asphalt in the 80’s and 90’s have not been satisfactory with regard to water sensitivity and deformation resistance of such asphalts.
In Europe the Netherlands have done more and later work with foamed asphalt for temperature reduction. A number of companies market such asphalt mixes but with use of foamed asphalt addition of chemical adhesion promoters is mandatory. Recent comparative trial work in Rotterdam has shown that even then such asphalt is significantly more sensitive to water and deformation than the comparative section with FT-wax [8].

7 Recycled Asphalt Pavements (RAP)
Warm mix technologies are used in conjunction with RAP, most often to improve compaction. A very new field of application is the recycling of asphalt at very high quantities in combination of FT-wax and rejuvenator it is possible, to fully recycle “old” asphalt pavements. The FT-wax enables a low mixing temperature of about 130 °C (266 °F), while the asphalt is restored to excellent properties with a selected rejuvenator [9]. The first application was done in 2006. In the year 2011 a number of roads in Germany were paved with this technology, including wearing courses composed of almost exclusively RAP. On May 17th 2011 the first fully recycled SMA was paved near Ulm in Bavaria.

8 Ground Tire Rubber
Due to the explosive price development of polymers such as SBS the use of tire rubber is increasingly getting into focus. In previous years this method of asphalt modification was not popular due to the significant emissions of fumes aerosols and especially unpleasant odours from such mixes. Also the high mix viscosity and subsequently the high energy consumption during manufacturing made this technology undesirable. The combination of tire rubber with viscosity reducing additives is a way out of the above dilemmas. The FGSV, the specification body in Germany, is preparing a paper on tire rubber and first regional specifications are passed in Bavaria. Both papers strongly recommend the use of viscosity reducing additives in order to keep the binder and mix temperatures below 180 °C (356 °F) at all times. It is assumed that above these temperatures constituents of the tire rubber will release harmful substances such as
benzothiazole.

9. Conclusions
Warm Mix asphalt or rather „viscosity reduced mixes“ can be used in Germany. Their share of the total market is relatively small but steadily growing, it is estimated at 5-8 %. Mainly wax based modifiers are used, FT-Waxes (Sasobit) have the biggest importance. The main trigger to use such products is enhanced deformation resistance and workability, especially in adverse weather conditions. After a lot of debate about the effect that waxes considerably stiffen the binders, performance in the field over almost 15 years has not substantiated any of the concerns about increased fatigue or cold temperature cracking. Methods such as PG grading would suggest such failures but they do not occur. Binder stiffening because of wax modification introduces stiffness via a different mode than ageing and does not increase brittleness. The author suggests that performance tests on asphalt specimens, if possible from plant produced samples, such as the TSRST fracture tests are a more holistic method for cold performance of warm mix asphalt. With 3% FT-wax modified warm mix asphalt can be used without any danger up to -30 °C (86°F).

Other technologies such as Zeolithes, chemical packs or foamed asphalt have so far not conquered significant market share because they offer no countable benefit other than temperature reduction where often cost for the technology is not offset by the achieved economic benefit.

References:

[9] Noedting, Riebesehl, Denck. Construction of a high quality asphalt wearing course with more than 90% reclaimed asphalt pavement (RAP); a case study, 16th Singapore Symposium on Pavement technology, Singapore, May 27th 2011