Case studies & non-highway applications; Success and failure from real practice

Practical experience in the viscosity modification of asphalt for performance or workability purposes in Germany

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Abstract

The application of viscosity modifying additives or viscosity modified bitumen in Germany traces back primarily to the reduction of the asphalt-temperature in order to fulfil health and safety requirements for the paving of mastic asphalt and to cost-savings at the asphalt production. The temperature reduction of asphalt is mandatory as well as implemented in the German technical specification in case of mastic asphalt since 2007. In addition, roller-compacted asphalt shall be laid temperature reduced since 2014 also, if placed in tunnels. But beyond working temperature reduction, the viscosity modification of roller-compacted asphalt offers also further potential ranging from better workability and compactability to an earlier road opening to traffic and to enhanced asphalt performance in practice. The application by reason of performance was shown for example on heavy trafficked motorways, logistics as well as port areas, and roundabouts. The advantage of better workability and compactability requires that the working temperature is kept, but allows laying or better results in special conditions such as unfavourable weather conditions, placing by hand, or geometry of the area. Because of the increasing application of viscosity modification, an advice on the classification of viscosity modified bitumen was published in Germany in 2016. Indeed, this allows an easier comparison of the different existing viscosity modified bitumen; but for viscosity modification of asphalt in general as well as in case of adding viscosity modifying additives at the mixing plant, suitable information concerning the application as well as formal guidelines still lack or notes are manufacturer- or product-specific. Therefore, some engineers or contracting authorities avoid viscosity modification, even if the performance or durability of the pavement could be improved by the application. The paper describes the successful experience with viscosity modification of asphalt in Germany on the basis of different applications and gives suitable information.

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1. INTRODUCTION

The main reason for the implementation and application of viscosity modifying additives in the context of asphalt pavements in Germany has been the reduction of the asphalt temperature in order to fulfil health and safety requirements for the paving of mastic asphalt. Another convincing incidental benefit are the cost-savings at the asphalt production as a consequence of temperature reduction.

In addition, viscosity modification of asphalt offers further potential such as better workability and compactibility, enhancing the asphalt performance or durability in practice, and earlier road opening. Especially the advantages of workability and performance or durability lead to an additional enlargement of the application of viscosity modification of asphalt.

2. APPLICATION OF VISCOSITY MODIFICATION IN GERMANY

The reduction of the mixing and consequently the paving temperature of mastic asphalt is mandatory in Germany since 2007 [1]. In addition, roller-compacted asphalt that is placed in tunnels shall be laid temperature reduced since 2014 also [2]. In 2016, recommendations on the classification of viscosity modified bitumen (E KvB [3]) were published, which allow an easier comparison and description of the different existing viscosity modified bitumen.

The viscosity modification of the asphalt can be achieved by adding the viscosity modifying additive during the asphalt mixing process or by direct use of viscosity modified bitumen, where the original bitumen may be either paving bitumen or polymer modified bitumen. Most of the available viscosity modifying additives are organic, but they can also be mineral. However, viscosity modified bitumen contains viscosity modifying organic additives only.

The viscosity modifying additive or viscosity modified bitumen, which may be used, shall be listed in the so-called collection of experience, which is administered and published by the Federal Highway Research Institute (BASt) [4]. For all listed products exist positive experience, which has to be proven by laboratory tests before the initial application, a test section with a reference section, and a follow-up examination of the test and reference sections conducted at least 5 years after the installation of the sections. To date, the listed organic additives are products, which consist of or contain fatty acid amide, Fischer-Tropsch-wax (FT-wax), and montan wax. The only mineral additive listed is a synthetic zeolite.

In order to achieve the positive effects of viscosity modification during paving or to enable temperature reduction, the viscosity modifying additives can be both organic and mineral. However, a change of the performance of the asphalt exist only for the organic additives.

The viscosity modifying organic additives are different hydrocarbon compounds with specific composition and structure, which therefore exhibit different melting or congealing points. Hence, they feature different phase transition temperatures in the bitumen modified with it. Below the congealing point, the viscosity reducing effect of the additive is eliminated, with the congealing of the additive usually resulting in an increase of the binder's viscosity and stiffness compared to the not modified bitumen.

This can also be seen by measurements with the dynamic shear rheometer (DSR): The shear modulus of the bitumen considerably increases in the presence of wax at test temperatures from 30°C to 90°C. However, the ageing susceptibility in case of wax-modification is reduced, so that the increase of stiffness due to ageing is less and the resulting stiffness remains almost constant. [5] Therefore, no detrimental effect on the performance at low service temperatures due to ageing is to be feared, while the resistance to rutting is increased, especially at early stage and for slow moving or even static load. This corresponds to the practical experience as exemplified below.

Recent research as well as the application of viscosity modified bitumen showed that the softening point ring and ball is no appropriate parameter to describe correct and simple the deformation behaviour in the upper temperature range of modified bitumen and the ageing state of the modified bitumen ([5], [6], [7]). Therefore, for viscosity modified bitumen, the so-called equivalent-stiffness-temperature is now used in Germany instead. The equivalent-stiffness-temperature was introduced for viscosity modified bitumen with the E KvB [3] and is measured with the DSR. It corresponds to the temperature at which the stiffness, which is measured as the complex shear modulus during the test, reaches 15kPa. In the test, the deformation of the specimen is controlled and kept constant, while the temperature is gradually increased (T-sweep according to [8]).

3. EXPERIENCE

3.1. BAB 1, border of Hamburg to motorway interchange Horster Dreieck

The motorway BAB 1 between the state border of Hamburg and the motorway interchange Horster Dreieck is counted among the most trafficked motorway sections in Lower Saxony. The averaged daily traffic added up to 102,000 vehicles per day in 2003, with nearly 15% heavy goods vehicles. The pavement of the carriageway Bremen (Fig. 1) was renewed on an 8km long section from April to October 2005.

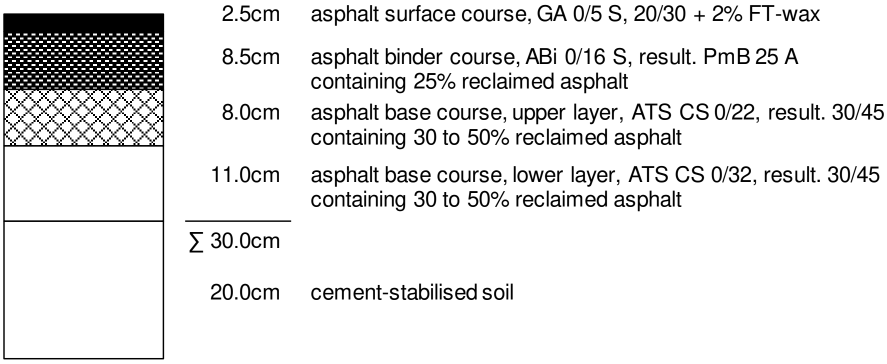

Figure 1: Structure of the pavement of BAB 1, border of Hamburg to motorway interchange Horster Dreieck, carriageway Bremen

In the past years, mastic asphalt surface courses were not installed in Lower Saxony, in particular because of their noise properties. With the design of the noise-optimised mastic asphalt 0/5 S, which is also highly resistant to deformation, a new design was available, which was tested on that section.

In the context of the extended mix design, the targeted adjustment of the viscosity of the mastic was focussed. For comparison, the mastic asphalt was mixed with paving bitumen 20/30, bitumen 20/30 modified with 2% FT-wax (SmB 20), and polymer modified bitumen PmB 25 A. The composition of the different mixes and the test results are listed in Table 1. The mastic asphalt with SmB 20 (viscosity modified bitumen) shows significantly higher resistance to deformation at elevated service temperatures than the mastic asphalt with paving bitumen 20/30 or polymer modified bitumen PmB 25 A. The low-temperature behaviour of the mastic asphalt with SmB 20 is roughly comparable to the performance of the asphalt with paving bitumen 20/30, both having a higher fracture temperature and a higher cryogenic tensile stress at fracture than the mastic asphalt with polymer modified bitumen.

However, the processing temperature of the mastic asphalt with viscosity modified bitumen SmB 20 is 220°C and thus 25K below the temperature of the mastic asphalt with the non-viscosity-modified bitumen, so that with the same processability significantly less vapours and aerosols escape and less energy is needed for production. Consequently, the laid mastic asphalt was designed with bitumen 20/30 modified with 2% FT-wax.

In the context of control tests on 26 samples, the binder content averaged 7.95M.-% and the dynamic penetration depth increased slightly to 1.21mm. The additional requirement for a dynamic penetration depth of at most 2mm was nevertheless fulfilled and the average dynamic penetration depth was also below the values of the asphalt mixes with bitumen 20/30 and PmB 25 A.

Altogether, the extended mix design and the control tests showed that a very deformation-resistant and at the same time very smooth and low-noise asphalt surface course was produced. The asphalt surface course of the 15.5m wide carriageway was paved in two strips, where the connection between the strips as well as the connection with structures and around installations were produced as a joint.

The first severe test occurred directly in the first year, which showed extreme weather conditions: The first winter after the asphalt pavement was laid was of long duration and with frequent frost-thaw changes. The following summer showed a long period of very hot days, in July several heat records, air temperatures on the day of often over 30°C and individual tropical nights (air temperature more than 20°C). When inspected at the beginning of August 2006, about one year after opening to traffic, there was no sign of deformation or rather rutting anywhere in the main lane or overtaking lane (Figure 2), while ruts had formed on many other motorways. Also, no cracks occurred.

Table 1. Mix design of mastic asphalt 0/5 S with different bitumen

characteristic and dimension / requirements and results	target value [9]	mix design GA 0/5 S with SmB 20	20/30	PmB 25 A
1. aggregate				
type of the coarse aggregate		Rhyolite	Rhyolite	Rhyolite
proportion ≤ 0.09 mm M.-%	24 – 34	27.7	28.1	27.7
proportion 0.09 to 2 mm M.-%		28.2	28.5	28.2
proportion > 2 mm M.-%	35 – 55	44.1	43.4	44.1
proportion 2 to 5 mm M.-%		40.9	40.3	40.9
proportion > 5 mm M.-%	≤ 10	3.2	3.1	3.2
crushed sand -natural sand - ratio	≥ 1 : 2	1.3 : 1	2 : 1	1.3 : 1
volume of aggregate Vol.-%		82.0	82.9	82.2
2. bitumen				
type of bitumen		SmB 20	20/30	PmB 25 A
binder content M.-%	7.0 to 8.5	7.7	7.3	7.7
binder volume Vol.-%		18.0	17.1	17.8
softening point ring and ball °C		79.0	62.6	68.0
3. properties of the specimen				
bulk density g/cm³		2.407	2.407	2.451
static penetration depth				
- after 0.5 h at 40 °C mm	1.0 to 2.0	1.6	1.9	1.7
- increase after another 0.5 h mm	≤ 0.4	0.3	0.4	0.3
4. additional tests				
dynamic penetration depth				
- after 0.5 h at 40 °C mm		0.80	2.55	1.89
- increase after another 0.5 h mm		0.23	0.72	0.56
low temperature cracking				
- fracture temperature °C	≤ −20	−21.00	−22.10	−24.20
- cryogenic tensile stress N/mm²		5.551	5.738	4.296
5. processing temperature °C		220	245	245

Figure 2: Overview of the motorway BAB 1 in August 2006

The second test took place with the renewal of the pavement in the opposite direction (to Hamburg) in 2007. During the construction the entire traffic was led on the carriageway to Bremen (5s+0-guidance) for several month. After the completion of the carriageway to Hamburg also no ruts or other damage on the lanes of the carriageway to Bremen were detected. So, the high load was very well borne by the asphalt pavement with viscosity modified mastic asphalt surface course.

Even today, after 14 or 12 years of use, both carriageways show perfect performance.

3.2. Roundabout

The pavement of a roundabout is exposed to special loadings with in particular high friction and shear forces. In order to avoid an underdimensioning of the pavement, German guidelines [10] provide in terms of the dimensioning of roundabouts for the choice of the next higher load class than that which applies to the most heavily trafficked road entering the roundabout.

The construction of the roundabout near to Aurich at the crossing of the state road L7 and the district road K40, which was previously controlled with traffic signals, was ordered in summer 2013. The state road L7 leads from the Lower Saxon district town Aurich to the North Sea coast and thus opens up the area north of Aurich for both, the local traffic and the touristic as well as freight traffic. With regard to traffic volume and the system as a roundabout, the traffic area was allocated to the load class Bk10, which is valid from 3.2 to 10.0 million equivalent 10-t-standard axles loads. The structure of the pavement depicts Fig. 3, but originally it was not intended to use viscosity modifying additives.

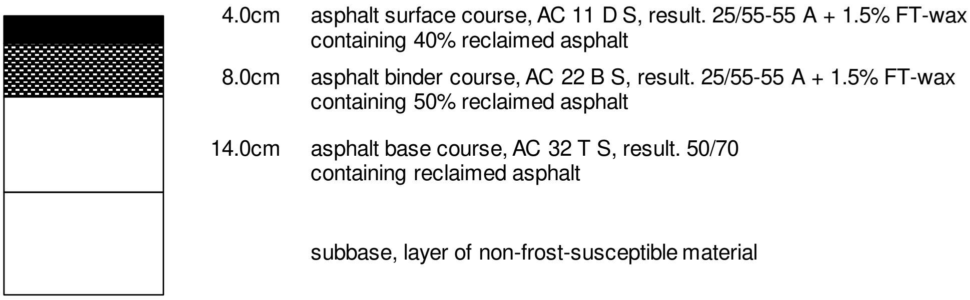

Figure 3: Structure of the pavement of the roundabout

The layer of non-frost-susceptible material was retained from the existing road pavement, but had to be placed as a soil replacement in the road widening area in consequence of the roundabout to improve the subsoil (turf) with low load-bearing capacity.

The outside diameter of the roundabouts is 38m with 7m circular lane width. In the middle of the roundabout is a green island with 13m diameter and the 5.5m wide inner ring was paved with grass pavers.

It was planned to complete the work at the beginning of December 2013, but due to delay the asphalt binder course as well as the asphalt surface course could be only paved in December 2013, when the air temperature ranged between 0°C and 5°C. In order to ensure a high paving quality and an adequate compaction, a viscosity modifying additive (FT-wax) was added to the asphalt at the initiative of the contractor and in consultation of the contracting authority, deviating from the original construction contract. So, the asphalt binder AC 16 B S contained 50% reclaimed and resulting polymer modified bitumen 25/55-55 A with 1.5% FT-wax, and the asphalt concrete for the asphalt surface course AC 11 D S contained 40% reclaimed asphalt and resulting polymer modified bitumen 25/55-55 A with 1.5% FT-wax as given in Fig. 3. The application of the viscosity modifying additive served in this case the better workability of the asphalt, a reduction of the mixing and paving temperature did not take place.

The placement of the asphalt surface course in the access and exit of the roundabout as well as the circular lane in the roundabout was done under full closure. The circular lane was paved over the entire width, only at the point between the beginning and the end of the strip in the circular lane as well as the connections to the access and exit lanes a seam was made.

In spite of the unfavourable weather conditions and the challenging geometry, all the courses of the asphalt pavement, especially the asphalt binder course and the asphalt surface course, are compliant with the requirements. The control tests prove that the asphalt courses are uniform and of high-quality. Likewise, the current condition of the roundabout offering a dense and smooth surface up to the edges of the road, sound seams, and no cracks after more than 5.5 years of traffic document a good performance of the asphalt pavement. This also applies to the manual laid areas, for example at the widening of the accesses and exits of the roundabout, in any gaps, and in the front of the directional islands.

Figure 4: Overview of the roundabout north of Aurich

3.3. Logistics and port handling area

As part of the construction of a new plant (Fig. 5) by a company that produces mega monopiles and transition pieces for the offshore wind industry, a logistics and port handling area was to be built in the west of Bremerhaven from November 2013 to September 2014. The building area of the plant is located in the outer area on the Weser. In order to be able to work flood-safe, the entire area was hydraulically filled with sand. The layer of filled sand was preloaded before the construction of the new plant started.

The plant was designed to process approximately 100,000t steel per year, which is delivered as large steel plates weighing about 35t by inland waterway vessels or rail. A finished monopile possesses a piece weight up to 2,400t and up to 120m length with up to 11m diameter, the transition pieces weight 500t in maximum with 35m length. The logistics and port handling area, which has a size of almost 99,000m², is used for both the handling or transhipment and the short-term storage of the raw materials as well as of the produced goods (Fig. 6); for the long-term storage of the monopiles and transition pieces another area was constructed afterwards. Consequently, on the logistics and port handling area, the load is very high and the loading is static but infrequent.

Thus, the structure of the pavement was calculated by means of computational dimensioning according to [11]. It consists of a durable asphalt surface course highly resistant to deformation and a very stable asphalt base course, which were built on a highly load bearing crushed aggregate base course and a layer of the prepared and compacted filled sand (Fig. 7). Similar pavement structures were successfully applied for example on the heavy load port area at the Niedersachsenkai [12], completed in 2012, as well as at the port of Hamburg and Wilhelmshaven.

In order to bear the loading without any settlement, the deformation modulus E_{V2} on the prepared and compacted sand had to be at least 80MPa and on the crushed rock base course 150MPa in minimum. Both, the asphalt concrete for the asphalt base course and the asphalt concrete for the asphalt surface course had to be designed specifically for the application on the logistics and port handling area. Thus, for the mix design, additional demands on the asphalt properties were made in order to ensure the design of an asphalt that is durable and highly resistant to deformation. For the same reason, it was required to add 2% FT-wax to the bitumen of the asphalt concrete for the asphalt surface course.

Figure 5: Overview of the logistics and port handling area of the monopile and transition pieces plant with two large cranes for the shipment

Figure 6: Transport of a monopile with a self-propelled modular transporter on the logistics and port handling area

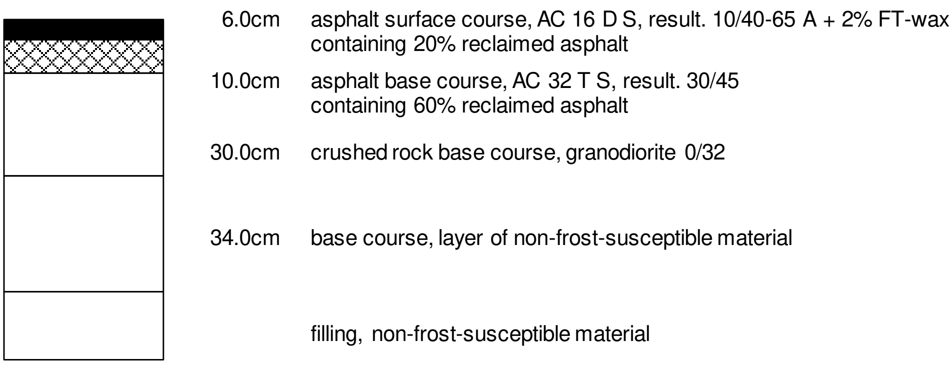

Figure 7: Structure of the pavement of the logistics and port handling area

The mix design and the target values given in the technical specifications or in the contract for the asphalt concrete for the asphalt surface course are listed in Table 2. The results of the additional tests indicate a good compactibility of the asphalt and, regarding the asphalt course, a very good low temperature performance, a high resistance to fatigue, and a high resistance to deformation at elevated service temperature. As part of the control test on the used asphalt, the determined fracture temperature slightly increased to −21.3°C in average, but still conforms to the target value, and the fatigue resistance was clearly higher, with about 281,000 cycles till failure.

Table 2. Mix design of asphalt concrete for asphalt surface courses AC 16 D S

characteristic and dimension \ requirements and results				target value	mix design AC 16 D S
1. aggregate					
type of the coarse aggregate					Granodiorite
proportion	≤ 0.063	mm	M.-%	5 to 9	8.6
proportion	0.063 to 2	mm	M.-%		29.9
proportion	> 2	mm	M.-%	55 to 65	61.5
proportion	> 11	mm	M.-%	≥ 15	17.5
proportion	> 16	mm	M.-%	≤ 10	1.7
stabilising additives			M.-%	0.2	0.2
proportion reclaimed asphalt			M.-%		20
2. bitumen					
type of bitumen				10/40-65 A RC + 2% FT-wax	10/40-65 A RC + 2% FT-wax
softening point ring and ball			°C	≥ 65	80.2
binder content			M.-%	≥ 5.1	5.3
binder volume			Vol.-%		12.8
3. properties of the asphalt					
bulk density (Marshall)			g/cm³		2.464
voids content (Marshall)			Vol.-%	2.5 to 3.5	3.0
4. additional tests					
compaction resistance T (135°C)			21 Nm		27.8
low temperature cracking (5°C)					
- fracture temperature			°C	≤ −15	−22.9
- cryogenic tensile stress			N/mm²		4.923
fatigue resistance			cycles n	≥ 50,000	94,510
rutting test (water bath, 50°C)			mm	≤ 3.5	2.4

In order to enhance the homogeneity and quality of the pavement and to ensure a continuous placement of the asphalt courses a feeder had to be used. The width of the strips should be up to 8.5m to reduce the numbers of seams. In view of the size of the paved area, however, all seams and all connections in the asphalt course had to be formed as a joint to avoid cracking.

For the finished asphalt courses, it was required that the rate of compaction in the asphalt base course be at least 99.0% with a voids content of 2.0Vol.-% to 7.0Vol.-%. In the asphalt surface course, the rate of compaction had to be at least 99.0% with a voids content of 1.5Vol.-% to 5.5 Vol.-%. These demands were met, where the rate of compaction averaged 99.0% in the asphalt surface course and 100.6% in the asphalt base course; the voids content was 3.1Vol.-% and 2.8Vol.-% respectively.

The past 5 years of usage proved a good performance of the pavement (Fig. 7). No relevant deformation and no cracks occurred despite of the challenging temperatures during the summer 2018 and 2019 or in winter 2016/17.

4. CONCLUSION

The main advantages of the application of viscosity modifying additives are first of all in the reasons for their development: reduction of fumes and aerosols from bitumen when placing temperature reduced asphalt (work safety) and saving energy and cost in the production of asphalt, when mixing the asphalt with reduced temperature. According to measurements during asphalt paving, the value of fumes and aerosols can be reduced by up to 60% in the open air and up to 80% in the tunnel (possessing a higher comparative concentration) [13].

Accompanied with the temperature reduction, the carbon dioxide emissions and the wear of the asphalt mixing plant are reduced, the bitumen is less stressed and aged. If the temperature is only slightly lowered, the asphalt has better workability and compactibility, allowing it to be safely laid in adverse weather conditions, when using highly viscous bitumen, or when laid manually. However, these possibilities that arise with the modification in viscosity should not be overtaxed to ensure quality and, in case of organic additives, to be able to use the improved asphalt performance in the long term.

The advantage of using ready-to-use viscosity modified bitumen is to assure a homogeneous dispersion as well as an equal content of the additive in the bitumen and, thus, in the asphalt throughout the numerous batches of the asphalt production. But the viscosity modifying additive may also be added only at the asphalt mixing plant e.g. after melting in a separate facility (in the case of organic additives), automatically via a metering system or by direct manual addition in the mixer.

Admittedly, the possibly additionally required technical equipment at the asphalt mixing plant may pose a barrier for the application of viscosity modifying additives. Also, the construction company should have experience in the production and laying of viscosity modified asphalt in order to make any necessary suitable adjustments to the conditions.

However, the benefits of as well as experience with viscosity modified asphalts clarify that their use pays off in many ways.

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