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Important Properties of the SMA Asphalts – Stone Mastic Asphalts

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ABSTRACT

For more than 40 years, Stone Mastic Asphalt has developed into an extremely successful asphalt construction method on a wide variety of traffic surfaces, not only in Austria and Germany, but worldwide. Stone Mastic Asphalt is based on the principle of a "self-supporting chippings framework" as well as on a high binder content through the use of fibrous material. The low void content makes the finished SMA layer practically impermeable to water. With properties such as versatile, durable, stable, wear-resistant, deformation-resistant and fatigue-resistant, Stone Mastic Asphalt meets the requirements of a modern road network, and road users, municipalities and the asphalt industry can all benefit from this.

Keywords: asphalt, bitumen, cellulose fibres, pavement, road construction, SMA asphalt, stabilising additives

INTRODUCTION

General

Definition of SMA asphalt

According to the standard ÖNORM EN 13108-5 Bituminous mixtures — Material specifications — Part 5: Stone Mastic Asphalt (consolidated version), *Splittmastixasphalt* (SMA asphalt) is an asphalt mix with precipitated aggregate and bitumen as a binder, built up from a framework of coarse crushed stone aggregates with a mastic mortar [ASI 2016].

Properties of SMA asphalt

Stone mastic asphalt (SMA) is - compared to asphalt concrete for asphalt wearing courses - characterised by an aggregate mixture with a significantly higher proportion of crushed coarse aggregates and precipitated aggregate, high binder content and stabilising additives. The very high content of crushed coarse aggregates, which are bonded by a binder-rich, mastic-like mortar, leads in the compacted state to an inherently supported, firmly braced aggregate framework, the durability of which under traffic loads requires a high impact and edge strength of the aggregates. Due to the failure grain size, so much mortar can be accommodated that the aggregates are thickly coated with mortar without compromising the resistance to deformation [DAV 2020].

The stabilising additives (e.g. fibrous materials) act as a binder carrier and have the task of holding the binder, which is "overdosed" in relation to the grain surface but required in this quantity, to the aggregates during production, transport and laying and preventing it from running off. Asphalt wearing courses made of SMA are very resistant to wear, deformation and fatigue (even at cold temperatures). The typical surface texture of SMA causes a reduction in tyre-road noise; a DStrO value of –2 dB(A) may be applied [DAV 2020].

Field of application of the SMA asphalt

Stone mastic asphalt wearing courses are particularly stable and durable. They have proven themselves excellently on traffic areas with the highest stresses from traffic and climate. Stone mastic asphalt can be used as a surface course on roads, paths and other traffic areas.

Stone Mastic Asphalt is now the standard construction method on motorways, federal and city roads with high and highest loads. SMA has also proven its worth on container parking areas with their extreme stresses [DAV 2000]. SMA asphalt is also used on airfields, roads and parking areas for service vehicles and buses, as well as industrial areas and factory sites.

A particular advantage of Stone Mastic Asphalt is that - within certain limits - it can be laid in uneven thickness for profile levelling without having to fear varying recompaction. The experience of more than 40 years has shown that wearing courses made of Stone Mastic Asphalt have an above-average service life due to their special design, which is based on the one hand on the high chippings content and on the other hand on the high binder and mortar content (Figure 1) (Table 1) [DAV 2000].

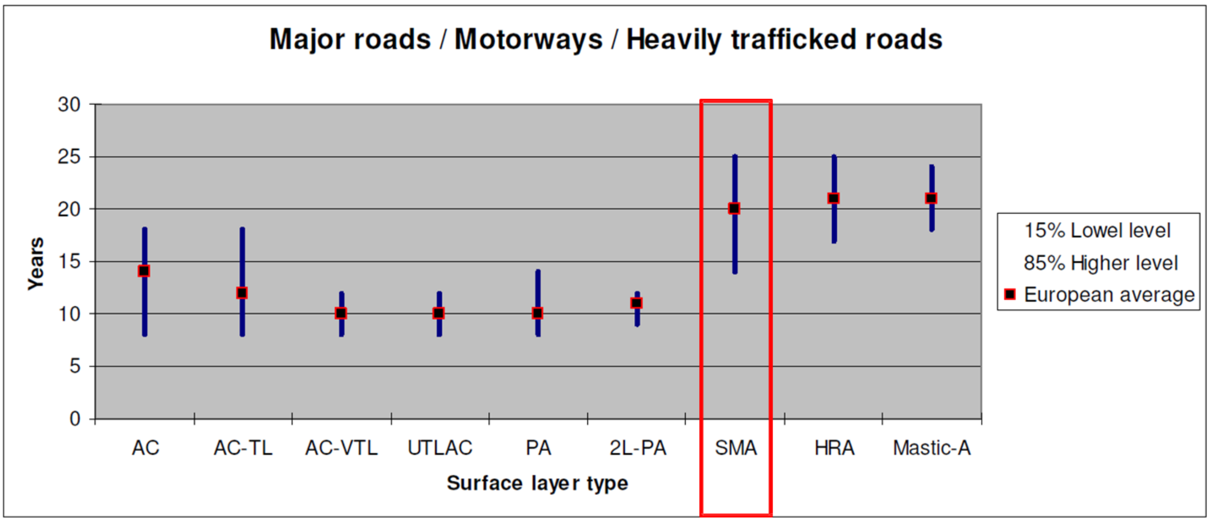

Figure 1. Comparison of the service life of asphalt wearing courses [EAPA 2007]

Table 1. Service life of asphalt wearing courses (in years) [EAPA 2007]

Autobahnen / Hauptverkehrsstraßen / stark befahrene Straßen

Major roads / motorways / heavily trafficked			
Type	15% Lowel level	European average	85% Higher level
AC	8	14	18
AC-TL 30-40 mm	8	12	18
AC-VTL 25-30 mm	8	10	12
UTLAC	8	10	12
PA	8	10	14
2L-PA [1])	9	11	12
SMA	14	20	25
HRA	17	21	25
Mastic-A	18	21	24

In addition to the generally applicable requirements for mineral aggregates for wearing courses, the strength and polishing resistance of the chippings are of particular importance for Stone Mastic Asphalt. Due to the low sand content, the fine roughness of the surface of Stone Mastic Asphalt wearing courses is almost exclusively caused by the roughness of the surface of the chippings. For roads of construction classes SV, I and II and for roads of construction class III with special stresses, grits with high polishing resistance, i.e. with a PSV value of at least 50, should therefore be used. In the case of special polishing stresses or other high requirements, it may also be necessary to use mineral aggregates or mineral aggregate mixtures with higher PSV values [DAV 2000].

SMA principle

The very high content of crushed coarse aggregates in SMA asphalt, which are bonded by a binder-rich mastic (mixture of filler, sand and bitumen), results in an inherently supported, firmly braced aggregate framework when compacted. The cellulose fibres are necessary as a stabilising additive to act as a binder carrier. They are intended to safely prevent the higher quantity of bitumen from running off the mineral aggregates, especially during storage, transport and installation of the asphalt mix. The principle sketch of the SMA asphalt is shown on Figure 2.

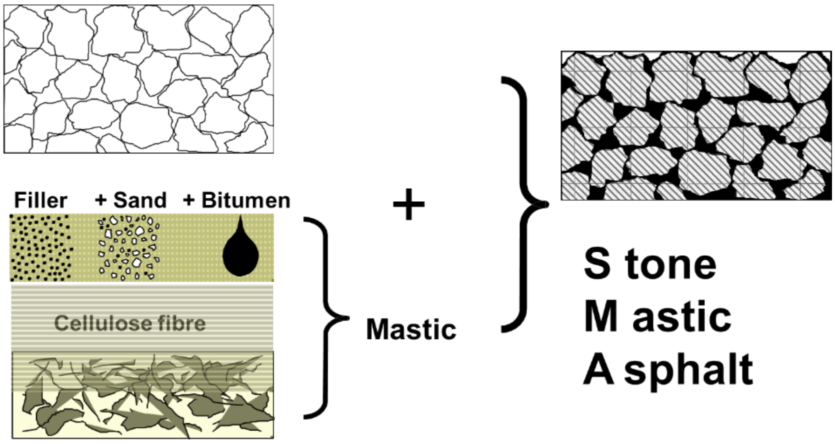

Figure 2. The principle sketch of the SMA asphalt [Gogolin 2015]

The comparison between SMA and asphalt concrete (AC)

On the principle representations of asphalt wearing course types, we can clearly see the difference between the SMA and asphalt concrete: The SMA split mastic asphalt is based and built on a failure aggregate principle (some aggregate groups fail), while the asphalt concrete (AC) has a steady aggregate size distribution, respectively all delivery aggregates are relatively evenly contained in the asphalt mix of the asphalt concrete (Figures 3, 4, 5, 6, 7).

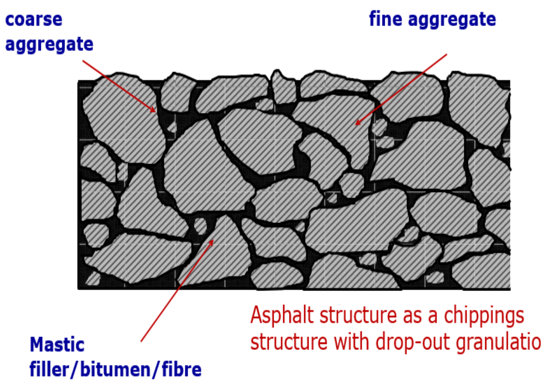

Figure 3. Stone Mastic Asphalt - SMA [Root n.y.]

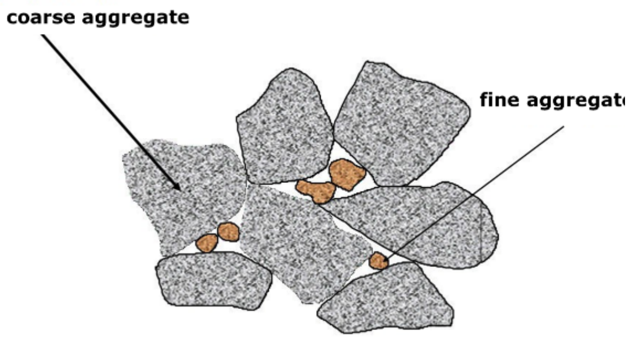

Figure 4. Stone Mastic Asphalt - SMA [Gogolin 2015]

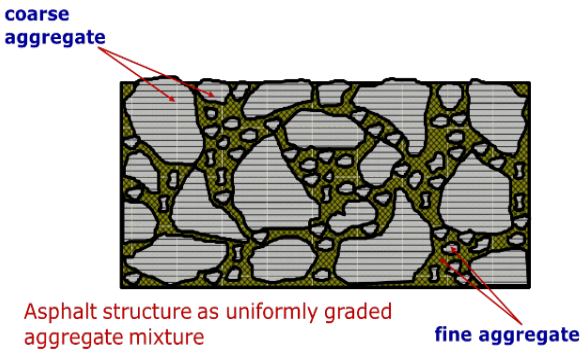

Figure 5. Asphalt concrete - AC [Root n.y.]

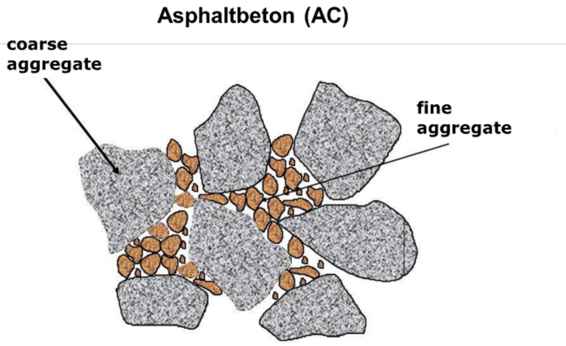

Figure 6. Asphalt concrete - AC [Gogolin 2015]

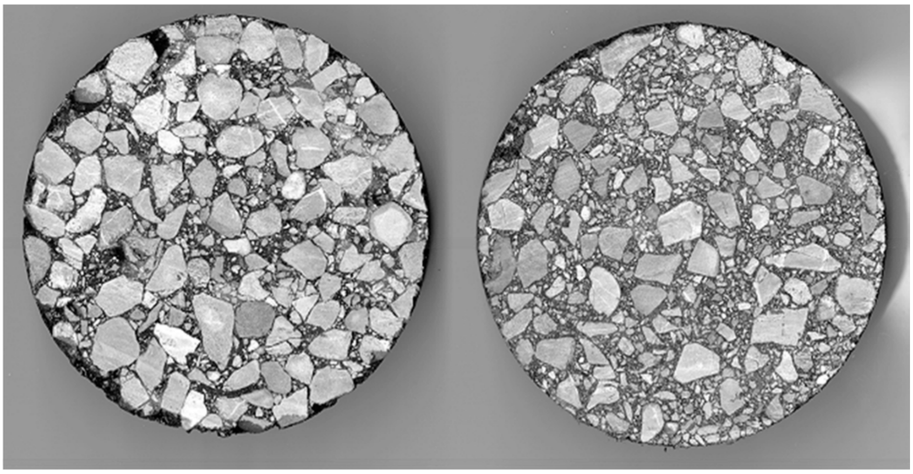

Figure 7. Direct comparison between SMA (left) and asphalt concrete (AC) (right) [Root n.y.]

SMA Asphalts in Germany

SMA mix composition in Germany

Marshall stability and flow value are practically unsuitable for assessing the deformation behaviour of Stone Mastic Asphalt. The relatively low Marshall stability of Stone Mastic Asphalts can even lead to a misjudgement of the deformation resistance compared to that of asphalt concrete. Today, the rutting test in accordance with TP A-StB Part: Rutting test - Determination of the rut depth in a water bath [FGSV 2007] is preferably used to evaluate the deformation resistance. It is suitable for the internal assessment of different compositions of stone mastic asphalts and their expected deformation properties. Due to the lack of sufficient evaluation background, no generally valid limit value for the rutting depths for Stone Mastic Asphalt can be named at present. The main properties of SMA asphalt according to [FGSV 2013], such as mineral aggregates, binders, stabilising additives, mix and layer, are shown in Table 2 [DAV 2000].

Table 2. "SMA" of the ZTV Asphalt-StB 2000 [DAV 2000]

Stone mastic asphalt	0/11 S	0/8 S	0/8	0/5
1. Mineral substance	Fine chipping, Fine chrushed sand, Rock powder		Fine chipping, Fine chrushed sand Natural sand, Rock powder	
Particle size mm	0/11	0/8		
Particle content < 0,09 mm M.-%	9 – 13	10 – 13	8 – 13	8 – 13
Particle content > 2,00 mm M.-%	73 – 80	73 – 80	70 – 80	60 – 70
Particle content > 5,00 mm M.-%	60 – 70	55 – 70	45 – 70	≤ 10
Particle content > 8,00 mm M.-%	≥ 40	≤ 10	≤ 10	–
Particle content > 11,20 mm M.-%	≤ 10	–	–	–
Crushed sand to natural sand ratio	1:0	1:0	≥ 1:1	≥ 1:1
2. Binder				
Binder sort	50/70 (PmB 45)[1)]	50/70 (PmB 45)[1)]	70/100	70/100 (160/220)[1)]
Binder content M.-%	≥ 6,5	≥ 7,0	≥ 7,0	≥ 7,2
3. Stabilizing additives				
Content in the mix M.-%	0,3 – 1,5			
4. Mixture				
Marshall specimens Compression temperature[2)] °C	135 ±5			
Void content Vol.-%	3,0 – 4,0	3,0 – 4,0	2,0 – 4,0	2,0 – 4,0
5. Layer				
Incorporation thickness cm	3,5 – 4,0	3,0 – 4,0	2,0 – 4,0	2,0 – 3,0
or Installation weight kg/m²	85 – 100	70 – 100	45 – 100	45 – 75
in exceptional cases, e.g. for uneven surfaces Incorporation thickness cm	2,5 – 5,0	2,0 – 4,0	–	–
or Installation weight kg/m²	60 – 125	45 – 100	–	–
compaction degree %	≥ 97			
Void content Vol.-%	≤ 6,0			

[1)] Only in special cases. [2)] The Marshall specimens shall be prepared at 145 ± 5°C when using PmB 45.

Comparison of grain size distributions in Germany between SMA 11 and AC 11

The total chippings content above 2.0 mm can only be varied to a very limited extent. It should be oriented towards the lower limit value for the S surfacings in order to avoid the risk of different void contents in the SMA surface course in the event of unavoidable production fluctuations [DAV 2000].

A direct comparison of the particle size distributions between the German asphalt types can be seen in Figure 8: SMA 11 S (left) and AC 11 D S (right). It is striking, for example, that between 20 and 30 wt.% passes through the 2 mm sieve in the case of SMA 11 S and twice as much, between 40 and 50 wt.%, in the case of AC 11 D S with the same sieve (Figure 8).

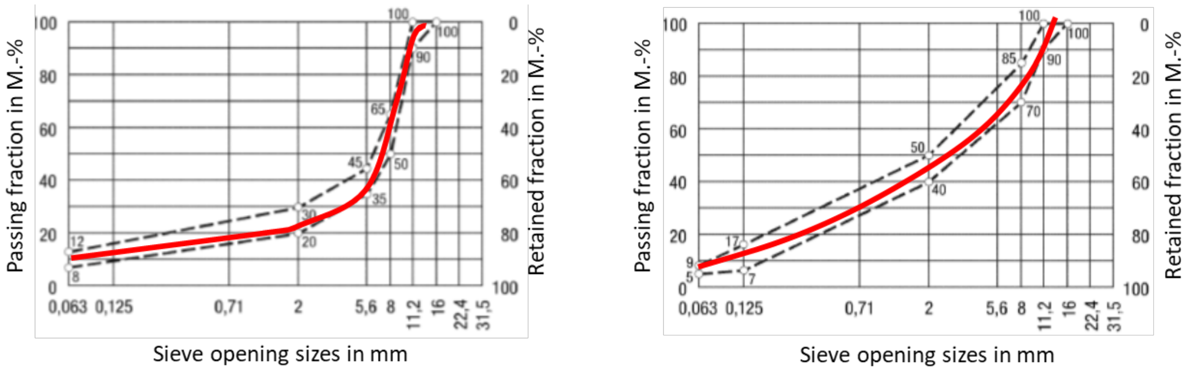

Figure 8. Comparison of particle size distributions between SMA 11 S (left) and AC 11 D S (right) [Otto 2013]

SMA Asphalts in Austria

A research project with SMA asphalts in Austria

Within the framework of the research project, design fundamentals for the requirements of asphalt constructions for highly stressed traffic areas are to be formulated. In addition, the bitumen-bound structure is to be optimised for the relevant traffic and climatic boundary conditions. This is done with the help of the fundamental asphalt tests developed at the Christian Doppler Laboratory of the Institute of Road Construction and Maintenance. The tests were carried out on a bituminous surface course type - chippings-mastic asphalt SMA 11 - and on a bituminous binder course type - AC 22 binder - and optimised with regard to their performance. The asphalt types tested are specified below [Hauser 2008]:

• **SMA 11:**

- Binder content: 5.1 - 5.3 - 5.5 [M-%].
- Binder: PmB 45/80-65
- Additives: Viatop Premium (0.2 M-%), Sasobit (3 %)
- Minerals: filler, LD slag (0/2, 2/4, 4/8, 8/11)

• **AC 22 binder:**

- Binder content: 4.2 - 4.5 - 4.8 - 5.1 [M-%].
- Binder: PmB 25/55-65
- Additive: Sasobit (3 %)
- Minerals: filler, LD slag (0/2, 2/4, 4/8, 8/11, 11/16, 16/22), serpentinite (0/2, 2/4, 4/8, 8/11, 11/16).

Within the framework of the initial type test and with the help of the numerical prediction methods, the following structure variants were examined:

• **Variant I:**

3,5 cm SMA 11 - PmB45/80-65 or
3,5 cm AC 11 deck - PmB45/80-65
21 cm AC 22 binder - PmB25/55-65 (3 lays a 7 cm)

• **Variant II:**

3,5 cm SMA 11 - PmB45/80-65 or
3,5 cm AC 11 deck - PmB45/80-65
9 cm AC 22 binder - PmB25/55-65
12 cm AC 32 trag - B50/70

• **Variant III:**

3,5 cm SMA 11 - PmB45/80-65 or
3,5 cm AC 11 deck - PmB45/80-65
21 cm AC 32 binder - PmB25/55-65 (1. lay 10 cm, 2. lay 11cm)

Low temperature behaviour

The low-temperature behaviour is assessed by means of cooling tests on prismatic asphalt specimens in accordance with standard ÖNORM B 3590 [ASI 2007]. The weather-related cooling of the road and the associated shrinkage and increase of the temperature-related, so-called cryogenic tensile stresses are simulated [Hauser 2008].

In the laboratory test, the specimen is cooled continuously at a cooling rate of $\Delta T = -10$ K/h at a starting temperature of +10 °C while keeping its length constant until failure. The force that increases with decreasing temperature is recorded and given as the cryogenic tensile stress curve in relation to the specimen cross-section. Further results are the fracture stress σ_{kry} and the crack temperature T_C at the onset of the fracture. The results of the cooling tests are shown graphically in Figure 9 (course of the average crack temperatures) and in Figure 10 (course of the average fracture stresses). It can be seen that the determined crack temperatures and stresses for the asphalt mixes tested are largely dependent on the cold properties of the binder (binder type), while the variation of the binder content does not cause any significant change in the crack temperatures [Hauser 2008].

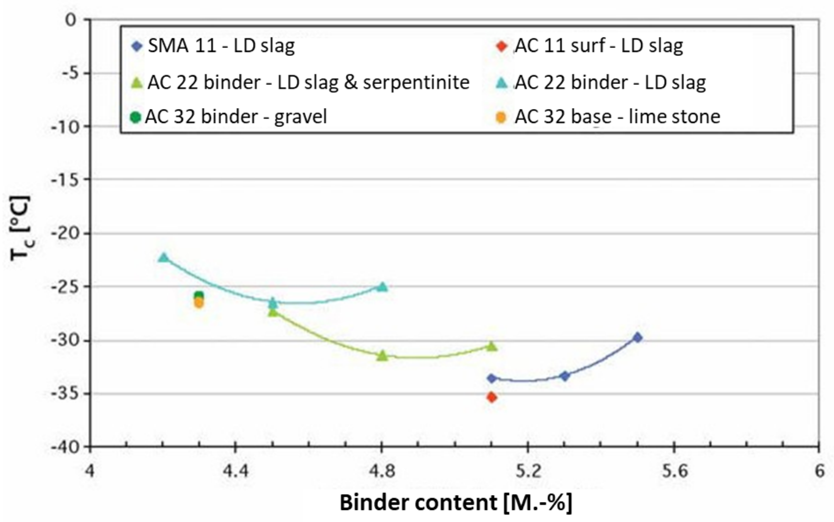

Figure 9. Course of the mean crack temperatures T_C [°C] as a function of the binder content for the mix types of the surface, binder and base layers [Hauser 2008]

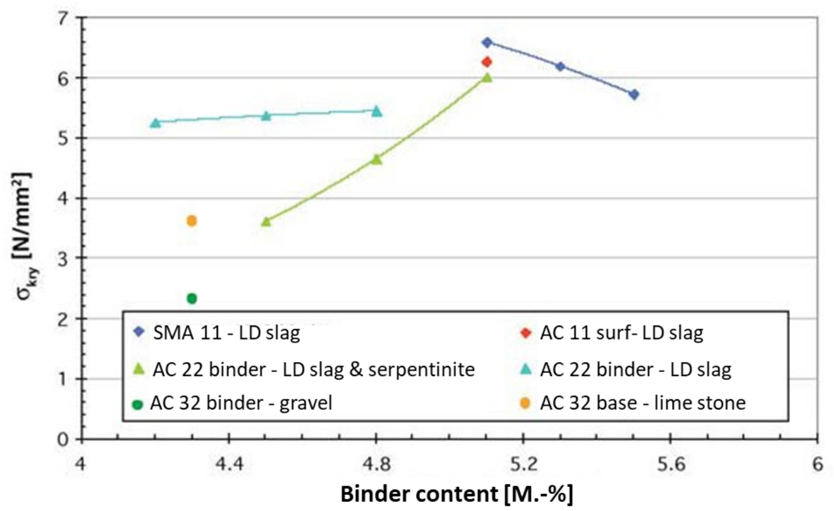

Figure 10. Course of the mean breaking stresses σ_{kry} [N/mm^2] as a function of the binder content for the mix types of the surface, binder and base layers [Hauser 2008]

Stiffness behaviour

The evaluation of the stiffness behaviour over a temperature range of –10 to +45 °C is based on the results from the stiffness test on the 4-point bending beam according to ÖNORM EN 12697-26 bituminous mixtures - Test methods - Part 26: Stiffness, Annex B [ASI 2018]. In this test, a prismatic asphalt specimen is subjected to a sinusoidal bending test at constant temperature. The bending is achieved by moving the central load points in a vertical direction perpendicular to the longitudinal axis of the specimen. The test is displacement-controlled with constant deflection (ε = 50 µm/m, damage-free loading) applied to the specimen via the path of the load piston (Figure 11) [Hauser 2008].

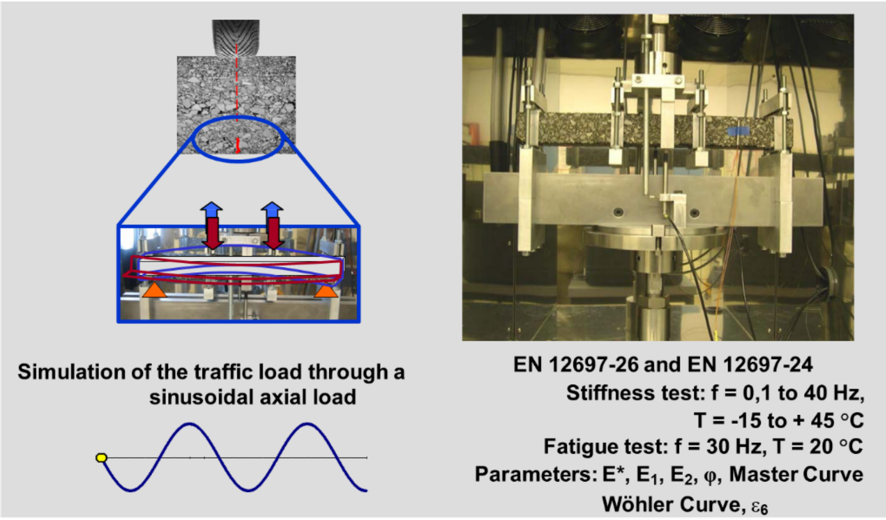

Figure 11. GMO mix optimisation - stiffness and fatigue behaviour [Hauser 2008]

During the test procedure, on the one hand the force signal σ(t), which is required to obtain a constant displacement amplitude, and on the other hand the deflections ε(t) obtained at the central underside of the test specimen are measured and recorded. From this, the temperature- and frequency-dependent stiffness modulus of the material, the so-called complex E-modulus E* and the phase shift angle φ are derived. From the results obtained, the master curves of the individual mixtures are calculated using the time-temperature superposition principle.

The master curves of the individual mixtures are derived (Figure 12), in order to be able to determine the relevant complex E-moduli of the asphalt mixes for any frequency and temperature range. The temperature-dependent asphalt stiffnesses derived in this way in the form of the dynamic E-modulus |E*| are shown in Figure 13 for a loading frequency of f = 10 Hz and are subsequently used as the basis for the fatigue calculations [Hauser 2008].

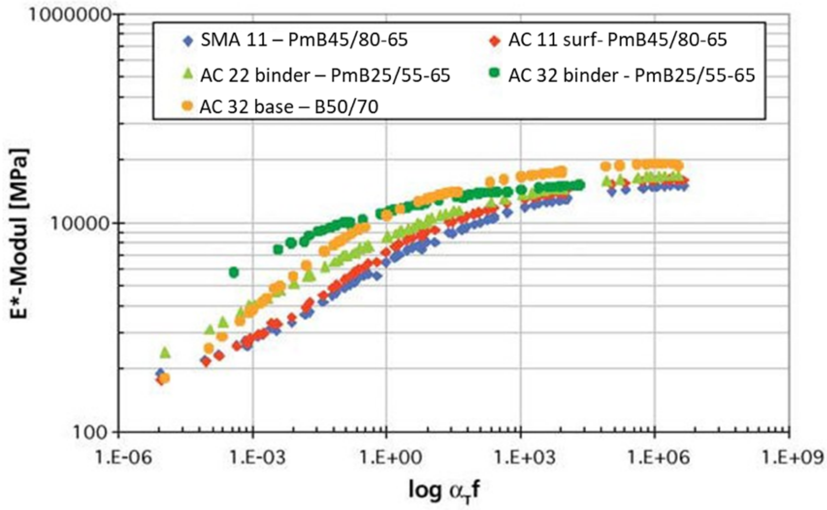

Figure 12. From the stiffness tests on the 4-point bending beam, master curves were determined for the mix types of the surface, binder and base layers [Hauser 2008]

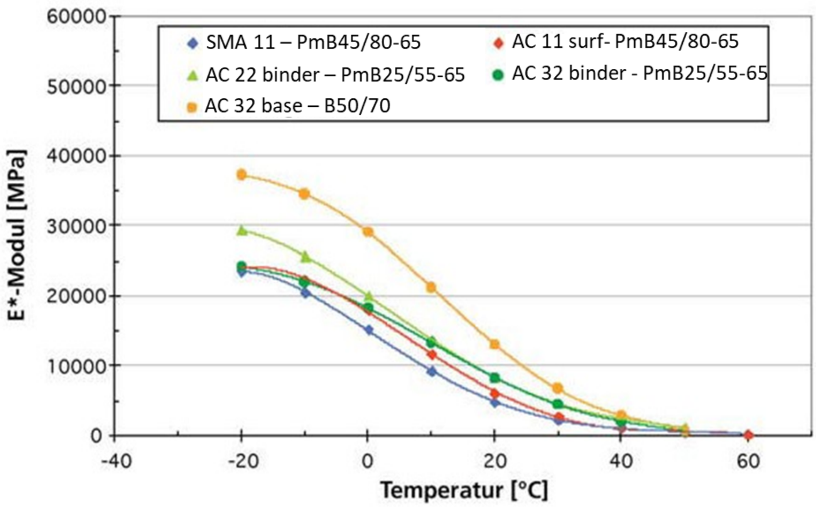

Figure 13. Asphalt mechanical parameters used in the determination of the relevant primary effects in the superstructure within the framework of the fatigue calculations (f = 10 Hz, v = 60 – 80 km/h) [Hauser 2008]

Installation Rules for the SMA Asphalt

The following rules apply to the installation of SMA asphalt in general [DAV 2000]:

- The temperature of the mix in the mixing bucket should be evenly distributed and, in the case of road bitumen 70/100, 50/70 or PmB 45 (without additional additives to improve processing), should not be lower than +150 °C. The temperature of the mix in the mixing bucket should be evenly distributed. Uniform temperature distribution means, for example, that no cold batches of mix should form in corners and angles.

- Depending on the paving speed, the road paver used must be set in such a way that it achieves an appropriate, i.e. not too high, pre-compaction (check e.g. with the isotope probe), at which no bouncing vibrations occur (structural loosening).

- In principle, rolling should be carried out as early as possible, i.e. close to the paver.

- At least two rollers must be used for each paving course.

- Roller compaction should be carried out with heavy tandem or tricycle rollers (service weight > 9 t).

- Vibration compaction should only be carried out at sufficiently high mix temperatures and after static pressing.

- Vibration is no longer permitted at layer temperatures below +100 °C. In the case of rigid substrates (e.g. concrete and paving) and layer thicknesses of less than 2 cm, vibration is generally not permitted, as this can lead to loosening and grain fragmentation.

- Rubber wheel rollers are ineffective for the compaction of SMA, may even be counterproductive for the surface properties and are generally no longer used.

- Necessary additional manual paving of Stone Mastic Asphalt must be carried out quickly, rapidly and, if possible, at the same time as the paving operation. Roller compaction should be carried out immediately after paving. The lack of pre-compaction of the paver is to be taken into account by a correspondingly higher paving thickness (rolling dimension).

Treatment of the surface of a SMA top layer

To increase the initial skid resistance, gritting measures as defined in ZTV Asphalt-StB [FGSV 2013] must be included in the specifications and carried out. The gritting quantity is usually 1 to 2 kg/m^2. In addition to 1/3 mm grit, dust-free and possibly lightly pre-bituminised 0.25/2 mm crushed sand has proven effective (Figure 14). If possible, grit 2/5 should not be used because of the higher noise emission [DAV 2000].

Figure 14. Installation of the gritting material [DAV 2000]

The gritting material can be applied either directly behind the paving screed or between the first rolling passes, but in any case it must be applied to the still sufficiently hot and bindable surface. In order to achieve a uniform surface appearance, the use of machine spreaders is essential (Figure 15 left). After paving, compaction and curing, a period of at least 24 hours should be allowed for the surface course to cool down before it is opened to traffic. Driving on the surface course earlier can lead to deformations in the wheel tracks [DAV 2000].

Figure 15. Non-blunted (left) and blunted (right) surfaces of Stone Mastic Asphalt wearing courses [DAV 2000]

TEST SECTIONS WITH SMA ASPHALT IN AUSTRIA

Introduction

As part of a research project financed by GESTRATA, the Christian Doppler (CD) Laboratory at the Vienna University of Technology was commissioned to design asphalt mixes for surface and binder courses for highly stressed traffic surfaces on the basis of performance-oriented (GVO) test methods. The mix formulations developed and optimised by means of GMO test methods were implemented in a further step in the mixing plants of Teerag-Asdag/Simmering and TAM in Nussdorf/Lower Austria and installed on two test sections on Vienna's Altmannsdorfer Strasse and a roundabout near St. Christophen/Lower Austria. The results of the condition assessment after the first year of operation were presented [Blab 2010].

Superstructure Construction of the Test Sections

The standard cross-section provides for a bituminous bound structure with 3.5 cm Stone Mastic Asphalt SMA 11 with a binder PmB 45/80-65 and an underlying 8 cm thick high-strength base course AC 22 binder with a binder PmB 25/55-65. Below this, a 12 cm thick base course AC 32 trag will be constructed. The unbound upper base course was made of 20 cm crushed aggregate over the unbound lower base course (frog protection layer 30 cm thick) (Figure 16). An admixture was added to each of the polymer-modified binders. The full-depth construction shown in Figure 16 was carried out on the test section in Vienna only at the intersections and partially on the first directional lane [Blab 2010].

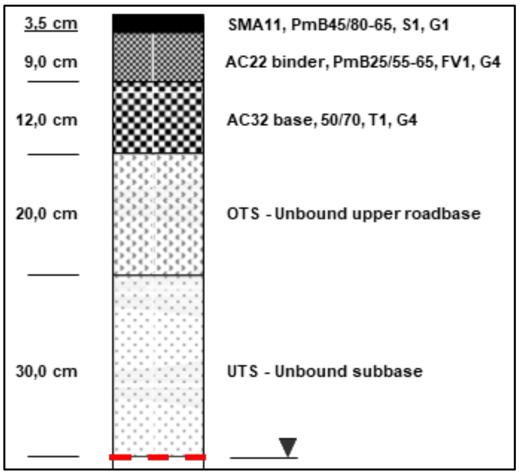

Figure 16. Road construction mi SMA asphalt on test section [Blab 2010] (edited by author)

Test section 1 - St. Christophen roundabout, Lower Austria

The roundabout on the B19 serves as a connection to the A1 West motorway junction, St. Christophen, and was constructed in two stages by the Lower Austrian Construction Department 2, Tulln, partly on the existing road. The asphalt paving took place on 23 and 24 October 2008, a total of approx. 2,200 m^2 of bituminous base and surface course was laid [Blab 2010].

The assessment of the deformation stability of the placed mix in the high-temperature range (rutting resistance) was carried out on the basis of triaxle tests with constant support pressure in accordance with standard ÖNORM EN 12697-25 Bituminous mixtures - Test methods - Part 25: Cyclic compression test [ASI 2016b] (Figure 17).

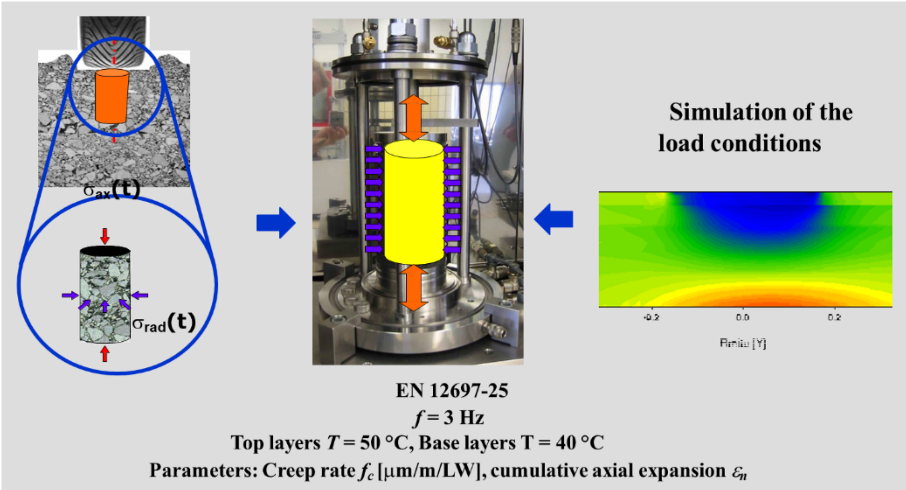

Figure 17. Triaxle tests with constant support pressure in accordance with standard ÖNORM EN 12697-25 [Hauser 2008]

Figure 18 shows the respective creep rates from the initial test, the trial mix and the mix material as an example for the test section KV St. Christophen for the DS material SMA 11. The requirements for deformation resistance according to the fundamental tender are fulfilled very well for the installed mix [Blab 2010].

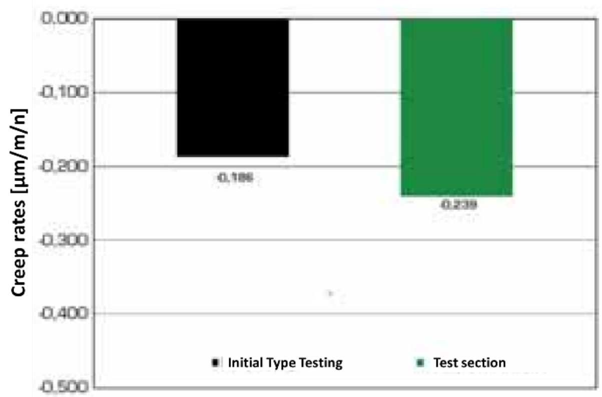

Figure 18. Creep rates of the investigated SMA 11 mixes, TAM Nussdorf [Blab 2010] (edited by author)

The assessment of the low-temperature behaviour of asphalt is carried out by means of cooling tests on prismatic asphalt specimens in accordance with Austrian standard ÖNORM B 3590 [ASI 2007]. The weather-related cooling of the road and the associated shrinkage and increase of the temperature-related, so-called cryogenic tensile stresses are simulated (Figure 19).

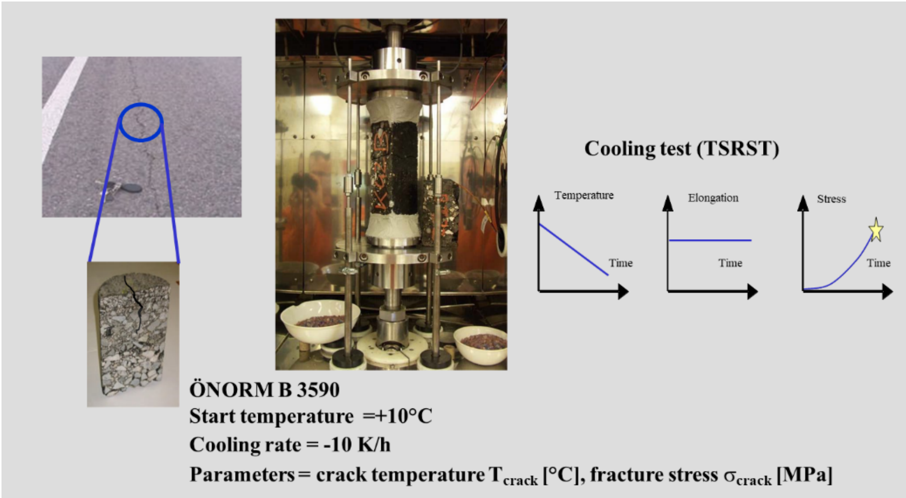

Figure 19. Cooling tests on prismatic asphalt specimens according to standard ÖNORM B 3590 [Hauser 2008]

Figure 20 shows the respective cryogenic tensile stress curves from the initial test and from the mix material from the test section KV St. Christophen for the surface course material SMA 11. The achievable crack temperature Tc-30 is just exceeded for the asphalt mix placed on the test section. Since the lowest air temperature measured in the St. Christophen area is –24.6 °C, the stone mastic mix installed in the test section can still be considered sufficiently resistant to low-temperature cracking [Blab 2010].

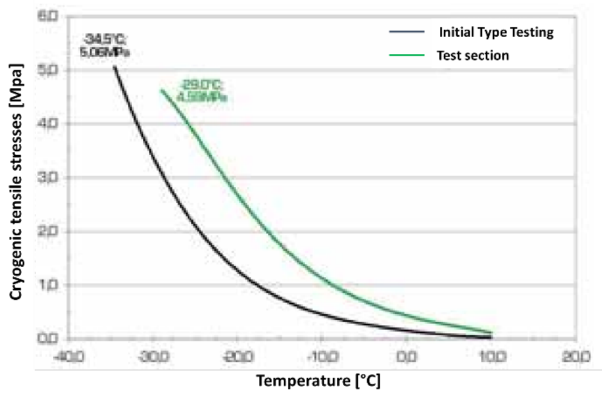

Figure 20. Results from the cooling tests of the top layer material SMA 11 from TAM Nussdorf [Blab 2010] (edited by author)

Test section 2 - Altmannsdorfer Straße, Vienna

On Altmannsdorfer Strasse in Vienna, the bituminous surface was repaired and partially renewed by the Vienna Magistrate MA 28, Road Administration and Road Construction, also in two construction stages. In October and November 2008, the pavement between Meischlgasse and Gennarogasse was rehabilitated in the direction towards the city, and in April 2009, the pavement between Rossakgasse and Meischlgasse was rehabilitated in the direction away from the city. In the course of both construction stages, a total of approx. 17,500 m^2 of base and surface course was laid [Blab 2010].

In order to follow the development of the unevenness and subsequently the rutting over the coming 5-year observation period, transverse unevenness measurements were carried out with the subgrade in April (zero measurement) and November 2009. The planum records the entire course of the unevenness relative to the 4 m long measuring bar. No significant rutting occurred on either of the test sections in summer 2009. After the first summer, permanent deformations of a maximum of 5 mm were only found in the area of the bus bay, where the buses with the heat-radiating low-floor engine have longer standing times. In the area of the bus bay, however, only the surface was repaired and not the entire bituminous structure. Overall, the rut depths on both test tracks are still within the target value of 5 mm defined in RVS 13.01.15 [FSV 2006] (condition class "very good") [Blab 2010].

CONCLUSION

Stone mastic asphalt was conceived in the mid-1960s as an asphalt wearing course with particularly high resistance to spiking. It was a further development and mechanisation of the asphalt mastic surface course, in which asphalt mastic was applied to the road surface by hand or with distribution boxes and then 5/8 or 8/11 high-grade chippings were spread and rolled in. Stone mastic asphalt is characterised by a similarly good durability and stability as mastic asphalt and can be transported and laid with the same equipment as asphalt concrete.

According to the definition of the ZTV Asphalt-StB [FGSV 2013], Stone Mastic Asphalt consists of a mineral mixture with aggregate, bitumen as a binder and stabilising additives, which have the task of acting as a binder carrier, preventing the binder from running off the minerals and favourably influencing the fatigue and ageing behaviour through the thick binder films that can be achieved with the additives. On the one hand, the high chippings content or binder content ensures a long service life, and on the other hand, the cavity-rich design achieves excellent noise reduction. The adsorption properties of Stone Mastic Asphalt enable a noise reduction of approx. 4 dB.

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