Stone Mastic Asphalt

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GUIDELINES

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PART A General

A.1 Foreword

Due to their numerous advantages, asphalt pavements assume a special significance in the creation of efficient, climate and environmentally friendly and sustainable mobility. As a construction material, asphalt already fulfils all the needs of

- road users,
- construction industry,
- the public,
- future generations.

Correctly designed asphalts fulfil all the requirements for a modern road network such as:

- sustainability,
- safety,
- driving comfort,
- cost efficiency/durability,
- noise reduction.

Stone Mastic Asphalts (SMA) are particularly characterized by their versatile performance properties, which can be tailored to the requirements of a construction project based on the desired composition.

A.2 Introduction and background

The asphalt pavement of a road usually comprises several asphalt courses, each fulfilling different tasks:

- asphalt surface course: Absorbing and distributing traffic loads, evenness, skid resistance, noise reduction, brightness, wear resistance, sealing against external influence;
- asphalt binder course: Distributing and transferring loads, especially the absorption of shear forces;
- asphalt base course: Transferring the loads to the underlying substructures.

The SMA pavement method originated in Germany at the end of the 1960s because studded tyres, used at that time during the winter season, milled deep ruts in the asphalt. Initially, ruts were eliminated by applying and distributing the asphalt mastic onto the surface, followed by spreading and rolling of coarse aggregates. That is, the origin of the Stone Mastic Asphalt was classified as the pavement method with „asphalt mastic with stone chippings“. The asphalt mastic in those days was initially applied to the road surface by hand or with distribution boxes and subsequently gritted with 5/8 or 8/11 chippings, which were then rolled in the surface (see Figure 1).

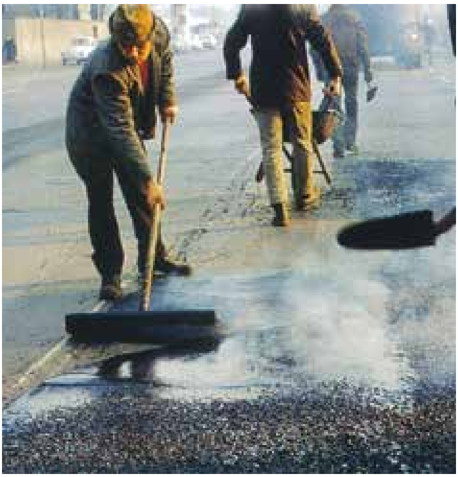


Figure 1: Paving an „asphalt mastic with a gritting“

This construction method proved to be very successful and quickly developed into a completely mechanised process of paving an asphalt surface course. A high coarse aggregate content with high-quality crushed aggregates and a bitumen-rich asphalt mastic (high mortar content) form until today the basic idea of the SMA asphalt technology, which has been incorporated into the name of this type of asphalt mixture.

After the ban of studded tyres in Germany in 1975, SMA construction method fell briefly into oblivion until rutting started emerging due to increased traffic loads. Previously gained experience showed that Stone Mastic Asphalt performs better against deformation and wear than asphalt concrete, which was the reason for SMA construction method to be revived and listed in the FGSV's (Road and Transportation Research Association) technical regulations in 1984.

The success story of SMA has continued over the next decades until today. Initially in Germany, then increasingly abroad in countries such as Great Britain, the Netherlands, Russia, China, the Scandinavian countries, Poland and Australia.

Over 50 years of SMA experience shows that these asphalt wearing courses exhibit a high resistance against deformation and provide a long service life thanks to their design. An even surface finish, skid resistance and freedom from cracks are additional requirements, which Stone Mastic Asphalt can fulfil. The material can be transported and paved with the same equipment like all other roller-compacted asphalt pavements.

Based on these characteristics and properties, the SMA principle was transferred to other applications. Particularly, low-noise asphalt wearing courses made of Stone Mastic Asphalt (SMA plus) were initially developed. Application of SMA surface course took place in 2005 on both federal motorways BAB 3 and BAB 93. Since then, this construction method has been further developed and enjoys now a great popularity in the municipal sector as well. In the meantime, the low-noise asphalt surface course made of SMA plus has become a recognised construction method.

Later on, the SMA principle was transferred from asphalt surface courses to asphalt binder courses. Particularly dense asphalt binder course designs with low tendency to segregation and very high deformation resistance (SMA binder) were created. Initial experience was gained back in mid-1980s at the Hanover Civil Engineering Office in the sector of bus traffic areas as well as in September 1993 on the BAB 8 motorway in Baden-Württemberg.

A.3 Stone Mastic Asphalt and its application areas

If properly designed and constructed, Stone Mastic Asphalt courses are considered to be very durable structures. Just like all asphalt courses, utilising Stone Mastic Asphalt should always be adapted to the local boundary conditions which exist. Table 1 shows the appropriate areas of application for all Stone Mastic Asphalts depending on the characteristic loads or stresses involved.

Table 1: Stone Mastic Asphalts for asphalt surface courses and their suitable areas of application depending on the characteristic loads or stresses

Classification Type of surface	Characteristic load or stress (LC) combinations	Load class according to RStO (Guidelines for the standardization of the pavement in the traffic areas)	SMA 11 S	SMA 8 S	SMA 5 S	SMA 5 plus	SMA 8 plus
Road traffic surfaces	Mainly rolling traffic with large proportion of heavy loads	LC100 – LC1.8	+	+	o	–	+
	Mainly rolling traffic with low proportion of heavy loads	LC1.0 to LC0.3	+	+	+	+	+
Municipal roads	Heavy-duty lane traffic, slow traffic	LC32 – LC3.2	+	+	–	o	–
		LC1.8 to LC0.3	+	+	–	o	–
	Frequent braking and acceleration, halt areas in front of traffic light	LC32 – LC0.3	–[1]	–[1]	–[1]	–[1]	–[1]
Bicycle paths and footpaths	Mostly not motorised vehicles	---	–	o	+	–	–
Roundabouts, turning bays	Turning on spot (surface areas under high shear stress)	---	–[1]	–[1]	–[1]	–[1]	–[1]
Bus traffic areas, parking areas for trucks, logistics and industrial areas	High point loads, turning on spot, special vehicles, special tyres	---	o[2]	–	–	–	–
Airside areas	Runways and taxiways	---	+	+	–	–	–

\+ Suitable o Partially suitable – Not suitable

1) Recommendations in the DAV Guidance "Asphalt in the municipal road construction"

2) Individual positive experience with a special composition (e.g. SMA 16)

A.3.1 Stone Mastic Asphalt for asphalt surface courses

Asphalt surface courses made of Stone Mastic Asphalt are considered to be particularly durable, resistant to deformation and provide good grip. They have proven themselves excellently in traffic areas with the highest loads or stresses created by traffic and climate.

Stone Mastic Asphalt consists of a gap-graded aggregate mix polymer-modified bitumen or straight-run bitumen as a binding agent and a stabilizing additive. This definition therefore provides the main characteristics of the composition for Stone Mastic Asphalt:

- high proportion of aggregates > 2 mm,
- high proportion of coarse aggregate,
- high binder content,
- stabilizing additive.

The aggregate mix, which has a high proportion of coarse aggregates, creates a grain structure with voids largely filled by mastic (bitumen, filler and stabilizing additive).

The stabilizing additives therefore have the task of acting as binder carriers. They prevent drainage of high quantities of bitumen during mixing, transporting, paving and compacting. Moreover, thicker bitumen films, which can be secured by utilising additives, have a beneficial effect on the durability of the asphalt layer, because thicker bitumen films age slower than thinner ones.

The predominant grain structure of Stone Mastic Asphalt with gap grading leads to a force-fit aggregate structure, which results in a high resistance to deformation.

If properly designed and paved, asphalt surface courses made of Stone Mastic Asphalt exhibit the following properties:

- high deformation resistance,
- high wear resistance,
- resistance to cracking when exposed to low temperature and mechanical stress,
- grainy surface texture,
- good macro roughness,
- good long-term behaviour / long service life.

SMA is considered a standard wearing course asphalt for motorways, urban highways, city and town streets with high stress or load conditions and in thinner sections for sub-urban roads with lower traffic loads. Apart from highway and road applications, SMA is beneficially utilised as wearing course in high stress and load areas such as ports and airports. Performance continues to be outstanding and cost-effective even in these days of increasingly hot summers.

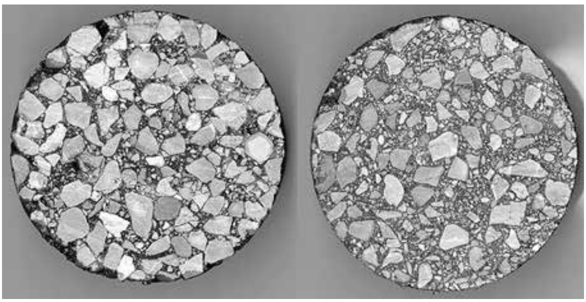


*Figure 2:
Core samples -
Asphalt surface course made of Stone Mastic Asphalt (left) and asphalt concrete (right)*

Gritting the surface area with an aggregate size of 1/3 is recommended.

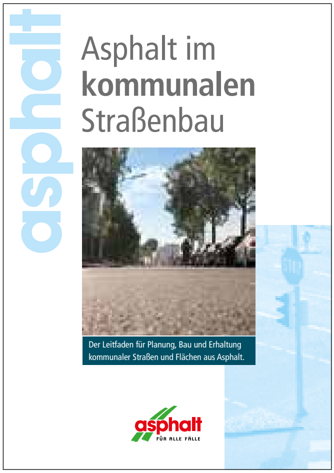


Figure 3:
DAV-Guidance
„Asphalt in municipal road construction“

Stone Mastic Asphalt is also well suited for the maintenance of traffic areas. Apart from SMA 5 for thin layers, SMA 8 can also be applied. One particular advantage of Stone Mastic Asphalt SMA 8 and SMA 11 is that - under certain limitation - it can also be paved for profiling in of uneven layers of various thicknesses without fearing significantly different degrees of post-compaction.

A.3.2 Stone Mastic Asphalt for noise-reducing asphalt surface courses

A variation of SMA, SMA plus, with altered aggregate composition and with higher voids content, can significantly reduce noise levels compared with AC, OGA and conventional SMA.

The modified aggregate composition of SMA plus leads to enhanced surface texture and in situ voids of 9-14%, producing lower noise generation and higher noise absorption.

SMA plus therefore offers, for use in residential areas , the long life of SMA together with appropriately low noise levels (refer to Figure 4).

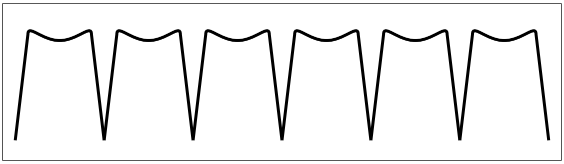


Figure 4:
Systematic representation of a concave surface area structure (plateaus and depressions)

Asphalt surface courses made of SMA plus are particularly suitable for streets with the speed limits of minimum 30 km/h.

Figure 5:
Asphalt surface course made of SMA plus

Figure 6: SMA plus under traffic

Figure 7: Surface area of SMA 8 plus

Ensuring the optimal noise-reducing effect always means that attention should be paid to longer road sections with a steady traffic flow. Applying SMA 5 plus and SMA 8 plus in these cases also depends on the maximum permitted speed according to Table 2, whereby SMA 8 plus also optimally develops its noise-reducing effect at speeds of at least 60 km/h.

Table 2: Suitable asphalt mixtures and types of asphalt

Permissible maximum speed [km/h]	$30 < v_{max} \leq 50$	$50 < v_{max} \leq 80$	$v_{max} > 80$
Asphalt mixture type and grade	SMA 5 plus	SMA 5 plus	SMA 8 plus
		SMA 8 plus	

When aggregates with particularly high polishing resistance are used, asphalt surface courses made of SMA plus demonstrate a high skid resistance. The surface area is not gritted, as this would adversely affect the surface texture. According to the available research data, gritting measures are also not required to increase the initial skid resistance.

If properly paved, SMA plus possesses the following properties:

- good noise reduction,
- high deformation resistance,
- good skid resistance

According to the experience to date, special drainage facilities are not required.

Based on the described design of the aggregates composition in SMA plus, a system characterised by a stone-to-stone support structure evolves. The individual aggregates are bonded by bitumen with special properties in order to provide the long-term durability. However, in traffic areas with particularly high shear and torsional stress, individual aggregates can be revealed. SMA plus in such areas is, therefore, subjected to technical limitations. Areas where SMA plus should not be implemented include traffic areas with narrow radii, especially with excessive turning and reversing traffic, bus bays, roundabouts, turning areas.

A.3.3 Stone Mastic Asphalt for asphalt binder courses

Asphalt binder courses made of Stone Mastic Asphalt are laid between the asphalt surface and base courses in traffic areas with high loads. According to the currently available data, the highest shear stress from the rolling traffic occurs in the asphalt binder course. Such stress can cause deformation under an unfavourable asphalt mix design. Therefore, a need to develop asphalt binder courses in accordance with the deformation-resistant stone mastic principle arose. Such binder courses have been paved successfully throughout Germany for many years and demonstrate the following advantages, when compared to conventional asphalt binder courses:

- high deformation resistance,
- high uniformity, easily achievable evenness and homogeneity of the surface area,
- low tendency to segregation,
- low void content, therefore high resistance to water penetration,
- good fatigue resistance,
- temporary suitability for traffic,
- suitable as a substrate for all asphalt surface courses,
- reduced risk of blistering in mastic asphalt surface courses (less water in substrate).

Asphalt binder courses made of Stone Mastic Asphalt are becoming increasingly important for areas with high traffic loads based on the predicted growth in the long-distance freight volume, mainly because they provide for a durable overall road structure and extend consecutive maintenance cycles of the road as a mode of transportation.

Figure 8:
Paving SMA binder course

Figure 9:
Compacted surface area of an SMA binder course

SMA binder course as a technology also contributes to the reduction of possible blistering occurring under asphalt surface courses made of mastic asphalt. Should SMA binder course be paved under a mastic asphalt, a minimum paving thickness of 7 cm (better 8 cm) should be specified and observed in order to achieve a closed surface texture.

PART B Technical rules and regulations

B.1 Basic principles

The valid German standards and technical rules and regulations for Stone Mastic Asphalt are listed in the appendix.

B.2 Stone Mastic Asphalt for asphalt surface courses

B.2.1 Material Requirements

- **Bitumen**

Polymer-modified bitumen is generally used for Stone Mastic Asphalt. Road straight run bitumen can also be used for areas with low loads.

Other types of bitumen can also be utilised in special cases. For example, 10/40-65 A bitumen can be applied for Stone Mastic Asphalt surface courses in case of especially high loads, such as altered or diverted routing on narrowed lanes.

When selecting the bitumen, the topographical and climatic conditions of the construction area should be taken into account in addition to the anticipated load.

Additives will increasingly be monitored in the future to limit occupational exposure to harmful vapours and aerosols from bitumen and also to conform to announced WMA requirements.

• Mineral aggregates

The requirements for mineral aggregates utilised in the production of Stone Mastic Asphalt for asphalt surface courses are listed in Table 3.

In order to comply with the requirements of process safety, pavement and appropriate service life, it is advisable to utilise at least 50 % by weight of < 0.063 mm aggregates (filler) from ground limestone powder (third-party filler).

The micro-roughness of the surface area of these asphalt surface courses is mainly caused by the roughness of aggregates > 2 mm because of the low proportion of aggregates < 2 mm in the mixture. Aggregates which indicate a PSV value of at least 51 should, therefore, be utilised for SMA surface courses.

If the Stone Mastic Asphalt surface courses are to be brightened, aggregates in the fraction sizes 2/5, 5/8 and 8/11 from natural and artificially brightened aggregates can be used depending on the maximum particle size in the asphalt mixture. If requirements for the brightness of a Stone Mastic Asphalt surface course are stipulated in the construction agreement, it can be achieved by adding one or several specified aggregates.

• Stabilizing additives

A high binder content in the Stone Mastic Asphalt aggregate mixture with a relatively low specific surface area of the aggregates requires an addition of stabilizing additives. They prevent the bitumen from drainage off the aggregates during production, storage, transport and paving processes.

In practice, cellulose fibers in pelletized or granulated form have proven to be the most suitable.

B.2.2 Requirements for the asphalt mixture composition

For Stone Mastic Asphalt surface courses, the following requirements for the asphalt mixture composition should apply according to the technical rules and regulations:

Table 3: Requirements for SMA surface courses

Designation	Unit	SMA 11 S	SMA 8 S	SMA 5 S
Aggregates (production size)				
Ratio crushed aggregate surface		$C_{100/0}$; $C_{95/1}$; $C_{90/1}$	$C_{100/0}$; $C_{95/1}$; $C_{90/1}$	$C_{100/0}$; $C_{95/1}$; $C_{90/1}$
Resistance to crushing		SZ_{18} / LA_{20}	SZ_{18} / LA_{20}	SZ_{18} / LA_{20}
Resistance to polishing		$PSV_{specified}$ (51)	$PSV_{specified}$ (51)	$PSV_{specified}$ (48)
Composition of asphalt mixture				
Passing sieve 16 mm	% by weight	100		
Passing sieve 11.2 mm	% by weight	90 to 100	100	
Passing sieve 8 mm	% by weight	50 to 65	90 to 100	100
Passing sieve 5.6 mm	% by weight	35 to 45	35 to 55	90 to 100
Passing sieve 2 mm	% by weight	20 to 30	20 to 30	30 to 40
Passing sieve 0.063 mm	% by weight	8 to 12	8 to 12	7 to 12
Minimum share of fine aggregates with E_{CS} 35	%	100	100	100
Binder				
Binder, type and grade		25/55-55 A	25/55-55 A	45/80-50 A
		50/70	50/70	50/70
				25/55-55 A
Binder content[1)]	% by weight	B_{min} 6.6	B_{min} 7.2	B_{min} 7.4
Stabilizing additive (cellulose fibers)				
Content in asphalt mixture	% by weight	0.3 – 1.5	0.3 – 1.5	0.3 – 1.5
Asphalt mixture				
Marshall specimen				
Void content in Marshall specimen	Vol.-%	V_{min} 2.5; V_{max} 3.0	V_{min} 2.5; V_{max} 3.0	V_{min} 2.0; V_{max} 3.0
Voids filled with bitumen	%	To be specified	To be specified	To be specified
Proportional rut depth	%	To be specified	To be specified	

1) In order to determine the respective minimum binder content, please multiply the indicated values by the factor $\alpha = 2{,}650/\rho_p$, where ρ_p is the dry density of the applied aggregate mixture

B.2.3 Requirements for the paved course

Table 4: Requirements for the paved SMA surface course

Designation	Unit	SMA 11 S	SMA 8 S	SMA 5 S
Paving thickness	cm	3.5 to 4.0	3.5 to 4.0	2.0 to 3.0
Degree of compaction	%	≥ 98.0	≥ 98.0	≥ 98.0
Void content	Vol.-%	≤ 5.0	≤ 5.0	≤ 5.0

B.3 Stone Mastic Asphalt for noise-reducing asphalt surface courses

B.3.1 Material Requirements

- **Bitumen**

Only Polymer-modified bitumen and ready-to-use polymer-modified bitumen are allowed for use for noise-reducing asphalt surface courses made of Stone Mastic Asphalt. The following bitumen grades are suitable: 40/100-65 A, 25/55-55 A, whereas 25/55-55 A should only be applied in justified special cases.

When selecting the bitumen, the topographical and climatic conditions of the construction area should be taken into account in addition to the anticipated load.

Additives will increasingly be monitored in the future to limit occupational exposure to harmful vapours and aerosols from bitumen and also to conform to announced WMA requirements.

• Mineral aggregates

In addition to the generally applicable requirements for aggregates for Stone Mastic Asphalt, the resistance to crushing and polishing of aggregates > 2 mm is of the particular importance. The micro-roughness of the surface area of such courses is mainly created by the roughness of aggregates > 2 mm due to the low proportion of aggregates < 2 mm. Aggregates with the resistance to polishing within the category „$PSV_{specified}$ (51)“ are, therefore, to be used for SMA plus.

The shape of the aggregates is a very important factor in attaining the void content required for noise reduction of the SMA plus wearing course. Experience shows that aggregates with a flat and spiky shape have an adverse effect on the void content, amount of voids filled with bitumen and the degree of compaction of the asphalt surface course.

• Stabilizing additives

A high binder content in the Stone Mastic Asphalt aggregate mixture with a relatively low specific surface area of the aggregates requires an addition of stabilizing additives. They prevent the bitumen from drainage off the aggregates during production, storage, transport and paving processes.

In practice, cellulose fibres in pelletized or granulated form have proven to be the most suitable.

B.3.2 Requirements for the asphalt mixture composition

SMA plus is an asphalt mixture with the void content specially designed for the noise-reducing effect. This asphalt mixture mainly differs from conventional Stone Mastic Asphalt surface courses by a modified aggregates composition. A lower proportion <2 mm aggregates results in an asphalt mixture with a higher void content compared to conventional Stone Mastic Asphalt, thus having a better macro-texture for noise reduction when paved.

Basically, a smaller maximum aggregate size is favourable for noise reduction, especially for passenger car tyres. In case of heavy load traffic and a speed limit over 50 km/h, a larger maximum aggregate size should be selected for the asphalt mixture.

In the case of Stone Mastic Asphalt for noise-reducing surface courses, the following requirements for the asphalt mixture composition should apply according to the technical rules and regulations:

Table 5: Requirements for SMA plus surface courses

Designation	Unit	SMA 8 plus	SMA 5 plus
Aggregates (production size)			
Ratio crushed aggregate surface		$C_{100/0}$; $C_{95/1}$; $C_{90/1}$	$C_{100/0}$; $C_{95/1}$; $C_{90/1}$
Resistance to crushing		SZ_{18} / LA_{20}	SZ_{18} / LA_{20}
Resistance to polishing		$PSV_{specified}$ (51)	$PSV_{specified}$ (51)
Composition of asphalt mixture		Coarse aggregates, fine aggregates, filler (limestone powder)	
Passing sieve 11.2 mm	% by weight	100	
Passing sieve 8 mm	% by weight	90 to 100	100
Passing sieve 5.6 mm	% by weight	20 to 30	85 to 100
Passing sieve 2 mm	% by weight	15 to 20	20 to 30
Passing sieve 0.063 mm	% by weight	6 to 8	7 to 10
Minimum share of fine aggregates with E_{CS} 35	%	100	100
Binder			
Binder, type and grade		40/100-65 A (25/55-55 A)[1]	40/100-65 A (25/55-55 A)[1]
Binder content[2]	% by weight	B_{min} 6.6	B_{min} 7.0
Binder volume		To be specified	To be specified
Stabilizing additive (cellulose fibers)			
Content in asphalt mixture	% by weight	≥ 0.30	≥ 0.15
Asphalt mixture			
Compaction temperature of Marshall specimen	°C	145 ± 5	145 ± 5
Void content in Marshall specimen	Vol.-%	V_{min} 9.0; V_{max} 11.0	V_{min} 9.0; V_{max} 11.0
Determining volumetric density according to		TP Asphalt Part 6, Method B	TP Asphalt Part 6, Method B
Voids filled with bitumen	%	To be specified	To be specified
Proportional rut depth	%	To be specified	To be specified

1 Up to load class LC1.8
2 In order to determine the respective minimum binder content, please multiply the indicated values by the factor $\alpha = 2{,}650/\rho_p$, where ρ_p is the dry density of the applied aggregate mixture
( ) in exceptional cases

B.3.3 Requirements for the paved course

Table 6: Requirements for the paved SMA plus surface course

Designation	Unit	SMA 8 plus	SMA 5 plus
Paving thickness	cm	2.5 to 4.0	2.0 to 3.0
Degree of compaction	%	≥ 97.0	≥ 97.0
Void content	Vol.-%	9.0 to 14.0	9.0 to 14.0

B.4 Stone Mastic Asphalt for asphalt binder courses

B.4.1 Material Requirements

- **Bitumen**

SMA binder courses should always be based on polymer-modified bitumen. The following bitumen grades are suitable: 10/40-65 A and 25/55-55 A, whereas 25/55-55 A should only be applied in justified special cases.

When selecting the bitumen, the topographical and climatic conditions of the construction area should be taken into account in addition to the anticipated load.

Additives will increasingly be monitored in the future to limit occupational exposure to harmful vapours and aerosols from bitumen and also to conform to announced WMA requirements.

• Mineral aggregates

The requirements for aggregates for the production of Stone Mastic Asphalt for asphalt binder courses correspond to those for Stone Mastic Asphalt.

The same basic principles are to be applied to the composition of Stone Mastic Asphalt for asphalt binder courses like those for Stone Mastic Asphalt for surface courses. The voids in the stone-to-stone supporting structure are largely filled with asphalt mastic, resulting in a dense SMA binder course with the high process reliability, resistance to deformation and to water penetration. Due to a high share of coarse aggregates >2 mm the edge strength of the used aggregates is of particular importance. In order to withstand the loads exerted during paving (compaction) and later under traffic, aggregates within the category of SZ_{18}/LA_{20} of the resistance to crushing should be applied in Stone Mastic Asphalt binder courses.

The aggregate composition has a significant influence on both void content and the pavement and compaction behaviour of Stone Mastic Asphalt. Experience gained to date with design, production and pavement of Stone Mastic Asphalt binder courses suggest the following ranges for aggregate sizes, as shown in Table 7.

Table 7: Ranges for optimum particle size distribution of Stone Mastic Asphalt for binder courses

Sieve size in mm	0.063	0.125	2.0	5.6	8.0	11.2	16.0	22.4
Passing sieve % by weight SMA 16 binder course	6 to 10	6 to 13	27 to 30	39 to 43	49 to 53	66 to 69	95 to 100	100
Passing sieve % by weight SMA 22 binder course	6 to 10	6 to 13	23 to 27	36 to 39	43 to 46	52 to 55	69 to 72	95 to 100

• Stabilizing additives

A high binder content in the Stone Mastic Asphalt aggregate mixture with a relatively low specific surface area of the aggregates requires an addition of stabilizing additives. They prevent the bitumen from drainage off the aggregates during production, storage, transport and paving processes.

In practice, cellulose fibres in pelletized or granulated form have proven to be the most suitable.

• RAP (Reclaimed Asphalt)

RAP can be utilised in the production of Stone Mastic Asphalt for asphalt binder courses.

Asphalt reclaimed from surface and binder courses is suitable for reuse in Stone Mastic Asphalt binder courses. The quantitative availability of this asphalt should be verified prior to beginning of the construction works. If special confirmation is provided, RAP of a different composition can also be applied.

Additions of RAP to Stone Mastic Asphalt binder courses are normally restricted to 30%. Larger quantities may be possible, but set higher requirements to the level of preparation and to the aggregates sieving curve in the reclaimed asphalt.

B.4.2 Requirements for the asphalt mixture composition

In case of Stone Mastic Asphalt for binder courses, the following requirements for the asphalt mixture composition should apply:

Table 8: Requirements for SMA binder courses

Designation	Unit	SMA 22 binder course	SMA 16 binder course
Aggregates (production size)			
Ratio crushed aggregate surface		$C_{100/0}$; $C_{95/1}$; $C_{90/1}$	$C_{100/0}$; $C_{95/1}$; $C_{90/1}$
Resistance to crushing		SZ_{18} / LA_{20}	SZ_{18} / LA_{20}
Composition of asphalt mixture		Coarse aggregates, fine aggregates, filler (limestone powder)	
Passing sieve 31.5 mm	% by weight	100	
Passing sieve 22.4 mm	% by weight	90 to 100	100
Passing sieve 16 mm	% by weight	65 to 75	90 to 100
Passing sieve 11.2 mm	% by weight	50 to 60	63 to 73
Passing sieve 8 mm	% by weight		46 to 56
Passing sieve 2 mm	% by weight	23 to 28	25 to 30
Passing sieve 0.063 mm	% by weight	6 to 10	6 to 10
Minimum share of fine aggregates with ECS 35	%	100	100
Binder			
Binder, type and grade		10/40-65 A[1] (25/55-55 A)[1]	10/40-65 A[1] (25/55-55 A)[1]
Binder content[2]	% by weight	B_{min} 4.8	B_{min} 5.2
Stabilizing additive (cellulose fibers)			
Content in asphalt mixture	% by weight	≥ 0.2	≥ 0.2
Asphalt mixture			
Marshall specimen			
Compaction temperature of Marshall specimen	°C	145 ± 5	145 ± 5
Void content in Marshall specimen	Vol.-%	V_{min} 3.0; V_{max} 4.0	V_{min} 3.0; V_{max} 4.0
Voids filled with bitumen	%	To be specified[3]	To be specified[3]
Proportional rut depth		$PRD_{Air\ 5.0}$	$PRD_{Air\ 5.0}$

(…) Type of bitumen in exceptional cases

1 If RAP is added, a 10/40-65 RC (25/55-55 RC) is required as the addition bitumen. The requirement for elastic recovery and thread length must be complied with during the control checks when using reclaimed asphalt

2 In order to determine the respective minimum binder content, please multiply the indicated values by the factor $\alpha = 2{,}650/\rho_p$, where ρ_p is the dry density of the applied aggregate mixture

3 Empirical values are in the range between 73 and 83 %

B.4.3 Requirements for the paved course

Table 9: Requirements for the paved SMA binder course

Designation	Unit	SMA 22 binder course	SMA 16 binder course
Paving thickness	cm	9.5 to 12.0	6.0 to 9.5
Degree of compaction	%	≥ 98.0	≥ 98.0
Void content	Vol.-%	1.5 to 5.5	1.5 to 5.5

PART C Production and pavement

C.1 General

C.1.1 Asphalt mixture design and initial testing

The characteristics of Stone Mastic Asphalt should be technically optimised with respect to the intended use and the desired performance properties required when designing the asphalt mix. When designing the mix, the project-related loads, stresses and the regional availability of the materials to be used must be considered, taking into account the technical regulations. Table 10 states some examples of possible loads or stresses:

Table 10: Project-related conditions for asphalt mix design

Project-related loads or stresses	Description
Position/location	Altitude (frost exposure zone) Forest area Solar radiation
Climatic conditions	Temperature differences / time-dependent temperature changes
Traffic load and volume of traffic	Narrow curves Lane driving (especially in construction areas) Slow driving Parking areas Road junction sections
Construction agreement	Construction method (e.g. compact asphalt) Course thickness

The aforementioned project-related loads or stresses must always be taken into account when selecting the type and grade of bitumen (soft/hard) as well as determining the aggregate composition (coarse/fine) and the bitumen content (high/low).

The decisive parameter in the design is the desired void content of the Marshall specimen. It must always lie within the specified ranges for the void content of the respective asphalt mixture type. Project-related loads must always be taken into account as well. It is advisable to determine the void content by varying the content of the binder. When no empirical values are available for determining the initial binder content, the minimum binder content, calculated according to the following formula, can serve as an initial reference value:

$$B_{min,\ calc.“} = \frac{\rho_{P,\ erw}}{2{,}650} \times \mathrm{B_{min}}$$

mit $B_{min,\ calc}$ = Calculated minimum binder content in % by weight

$\rho_{p,\ exp}$ = Expected dry density of the aggregate mixture in g/cm³

B_{min} = minimum binder content in % by weight according to the specifications

The value hereby represents the average reference for the variation of the binder content. Starting from this reference value, binder contents should be determined consecutively with steps of +/-0.3 % by weight. The mixtures with such three binder contents should be prepared in the laboratory for further tests.

The drainage test should be executed to evaluate the binder drainage. The drainage value should not exceed 0.2 % by weight.

Marshall specimen should be prepared at a compaction temperature of 135±5 °C when using road construction bitumen and at a compaction temperature of 145±5 °C when using polymer-modified bitumen.

Adjusting the void content by varying the binder content is technically reasonable only to a very limited extent. If, in addition to varying the binder content, further adjustments to the design are necessary to achieve the desired void content, it is advisable to amend the aggregate size composition in the following order:

- total coarse aggregate content > 2 mm,
- ratio of individual aggregate fractions > 2 mm,
- filler content (consider filler/bitumen ratio),
- ratio of baghouse filler to third-party filler.

Table 11: Recommended approximate composition of the individual particle fractions for SMA surface courses, based on the share of aggregates > 2 mm

Aggregate fraction	SMA 11 S	SMA 8 S
2/5	1 part	2 parts
5/8	2 parts	5 parts
8/11	4 parts	–

Evaluating the laboratory test mixes leads to an initial test, which defines the final composition of the Stone Mastic Asphalt.

Wide-scale production test trials at the asphalt mixing plant are recommended in order to verify process-reliable production practice and pavement behaviour.

In order to verify the compliance of the performance properties with the specified requirements, it is reasonable to execute additional tests on the asphalt mixture:

- assessing the deformation behaviour under heat in the pressure-swell test
- assessing the low-temperature behaviour
- assessing the sensitivity to water

C.1.2 Adjustments at the asphalt mixing plant and wide-scale technical mixing trials

Based on initial test data and knowledge of the technical specifications of the asphalt mixing plant, the mixing plant settings are made. They incorporate the requirements to initial dosing rates and weighing. In addition, the determination of the target asphalt mixture temperature and the hourly output is carried out. The initial settings at the mixing plant should be inspected for compliance with the initial test data, especially on the void content in the Marshall specimen, after a wide-scale technical mixing trial followed by an asphalt mixture analysis. In case of deviations, the process should be repeated with modified settings until the target values are achieved with a high degree of accuracy. The setting details of the mixing trials such as hourly initial cold dosing rates, burner setting level or hot bins output combinations (combined opening of hot bins for the biggest aggregate fraction) should be recorded because these settings can have a considerable influence on the composition of the asphalt mixture, depending on the production process. The target is to simulate the subsequent production process as realistically as possible.

A start-up sample should be taken at the beginning of the first production day and fully examined (asphalt mixture composition and properties). The objective of the procedure is to adjust the plant settings in order to correct any deviations in the composition of the mixture, which have occurred since the mixing trials.

C.1.3 Asphalt mixture production

The production of SMA is comparable to the production of any other type of rolled asphalt. Due to a high share of coarse aggregates, it is meaningful to apply two dosing units. The upper decks of the hot sieving process screens could be overloaded by the high amount of coarse aggregates, so that the screening effect can be impaired. The paving capacity should, therefore, match the output capacity and/or technical capabilities of the asphalt mixing plant (hot screening, dosing).

Due to low content of fine aggregates used in other types of asphalt mixture, coarse aggregates are more strongly heated in the drying drum, since the flame impacts them directlyand is not influenced by a dense sand veil. The burner output should, therefore, be regulated in such a way that the aggregate temperature is not too high and remains uniform throughout the entire production period. The temperature of the overall asphalt mixture is essential.

The stabilizing additives should be precisely added to the mixture according to their type and delivery form. Due to high effectiveness of such stabilizing additives, variations in the dosing quantities and distribution may strongly affect the properties of the Stone Mastic Asphalt and the paved courses. Therefore, only those stabilizing additives should be applied, which were homogeneously supplied and do not lose their homogeneity during storage and processing.

The production described below refers mainly to the addition of fiber materials. If granulates, liquid substances or filler-enriched additives are added, special features of these substances should be taken into account.

The packaging size and the batch sizes should match. Organic fiber materials must not become moist during storage and usage in order to avoid the formation of lumps and, therefore, to reduce the risk of uneven distribution in the asphalt mixture.

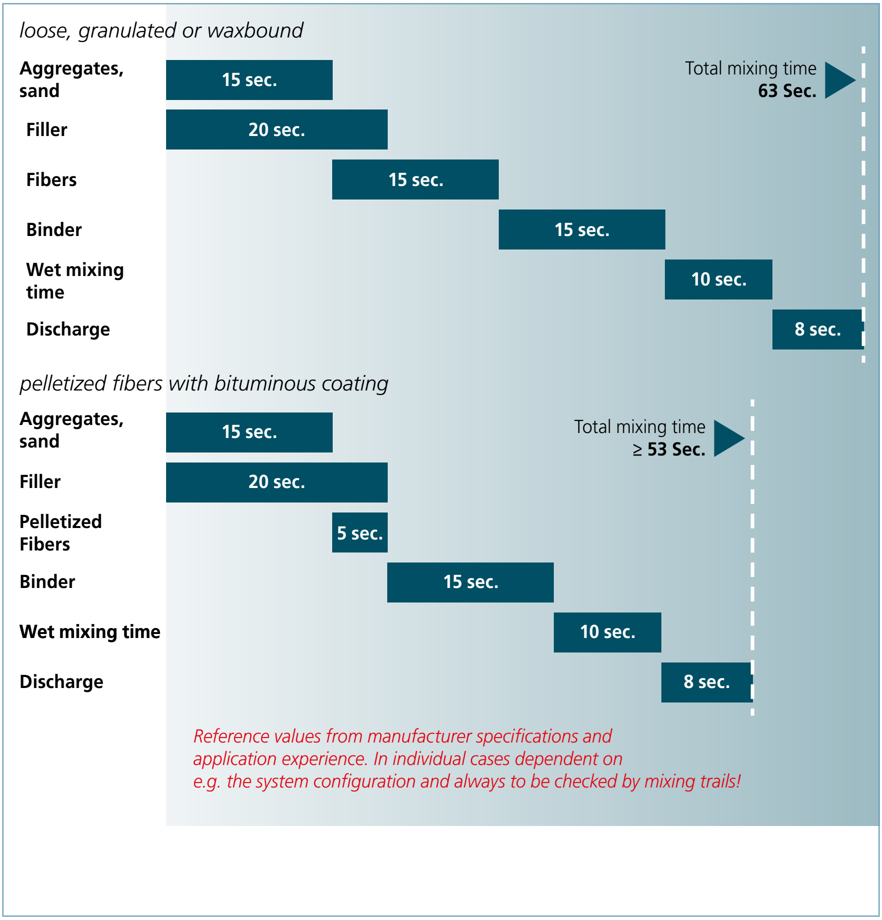
Feeding is usually performed automatically by appropriate equipment. Some manufacturers of stabilizing additives also provide special dosing equipment adapted to their material. In exceptional cases (e.g. small quantities), feeding can also be executed manually through a flap located on the mixer.

Since binder always accumulates on large surface areas, a homogeneous asphalt mixture can only be achieved by evenly distributed fiber additives. Possible recommendations of the fiber manufacturers should be observed. In case of fiber additives, it should be considered that their uniform distribution in the asphalt mixture occurs during the „post-mixing time" (i.e. during and after the addition of the bitumen). An excessive „dry mixing time" can lead to the fibers being milled to powder.

In case of granulated and wax bound fibers, they are sometimes insufficiently dispersed due to different pelletizing pressure or too short dry mixing time. It is, therefore, recommended to occasionally inspect the dispersion and homogeneous distribution of the fiber additives.

It should be noted that pre-mixing and post-mixing cycles result in a reduction of the mixing performance.

Figure 10: Recommendations for adding individual components and total mixing time when using cellulose fibers



During production of Stone Mastic Asphalt, any switching to other types of asphalt mixtures and grades, in particular asphalt base or binder courses, should be avoided, since this may cause, for example, changes in the

- burner settings,
- throughput capacity,
- sieving accuracy
  (composition of the aggregates in the hot bins).

Viscosity-altering binders or additives can be utilised.

C.1.4 Internal plant production control (PPC)

The control of the asphalt mix quality is secured by means of product tests within the plant production control (PPC). Additionally, the manufacturer can determine the sampling intervals and the scope of testing for each specific type of the product in accordance with own experience and expected uniformity of the construction materials. An increased scope of testing is recommended due to the narrow tolerance range in the void content in the Marshall specimen, when compared to other asphalt mixture types.

Sampling of the asphalt mixture is carried out directly from the aggregate material pile, preferably out of the transport vehicle from a sampling platform or from the filled loader bucket. In addition, a visual assessment of the entire loaded volume in a transport vehicle should be made in order to evaluate homogeneity (bulk cone, segregation, visual appearance). The associated temperature of the asphalt mixture should be measured. If deviations from the target temperature specified for the project are found, they should be eliminated via the burner settings at the asphalt mixing plant.

Particularly in case of Stone Mastic Asphalt, the shovel used for sampling must always be free of any binder or mixture residues, since they can have a direct influence on the binder content determined in the laboratory. In order to initially assess the drainage behaviour, it is recommended to observe the specific, time and temperature-dependent asphalt mix „adhesion pattern" on the inner side of sampling bucket, when emptying it in the laboratory (refer to Figure 11). A second sampling bucket should be filled with asphalt mixture and stored in a drying cabinet at 160 °C for at least one

hour. The assessment of the binder adhesion after emptying the sampling bucket can be either based on the previous experience or determined by the mass increase of the sampling bucket (differential weighing).

Figure 11:
Sample of the adherent binder in the sampling bucket

C.1.5 Interim storage and transport

Stone Mastic Asphalt like any other type of asphalt should not be kept in the storage silos for excessive periods in order to prevent any harmful alterations of the binder.

Generally, the application of thermally isolated vehicles (and feeders) provides higher asphalt mixture temperatures during their transportation and discharging in the paver.

The load surfaces of the transport vehicles must be clean. Only release agents suitable for asphalt or a thin water film may be used as sprays for the load surfaces. Diesel oil should not be used for reasons of quality assurance and occupational safety. In summer, transport vehicles must still be covered with wind-proof covers in order to prevent the cooling down of the asphalt mixture and harmful hardening of the binder due to oxidation from the contact with air oxygen. In case of small paving quantities and slow work progress (e.g. in urban road construction or repair works), thermally insulated lorry-mounted containers or thermally insulated semi-trailer lorries with horizontal conveying (Figure 12) have proven their particular effectiveness.

Figure 12: Thermally insulated semi-trailer lorry with horizontal conveying

Specifying the required delivery temperature is usually agreed with the person responsible for pavement on the construction site before production commences and depending on the paving and weather conditions on the construction day. The required use of thermally insulated transport vehicles limits the cooling of the asphalt mixture during the transportation. Based on the discharging temperature, the expected temperature at delivery can be calculated or estimated for the unloading into the paving vehicle. For the pavement and compaction of warm mix asphalt, only a limited time slot is available compared to conventional rolled asphalt.

C.1.6 Delivering from several asphalt mixing plants

When producing and delivering SMA from several asphalt mixing plants, the relevant initial test results should be technically matched up. The compatibility of the initial tests in terms of asphalt technology will ensure, in particular, uniform compaction behaviour on the construction site.

Furthermore, the asphalt mixtures temperatures among the supplier plants and the construction site should be additionally coordinated under consideration of the expected cooling behaviour (outside temperature, thermally insulated vehicles, storage time on the transport vehicle etc.).

C.2 Asphalt surface courses

C.2.1 Pavement and compaction

The operations of mixing, transportation and paving should be coordinated. A well-organized construction sequence can, on one hand, largely prevent unnecessary queuing time of the transport vehicles with associated losses of the asphalt mixture temperature and, on the other hand, avoid a downtime of the paver that may result in problems with compaction and longitudinal evenness. A continuous feeding of the paver with the asphalt mixture is an important prerequisite for the uniformity of texture and compaction as well as for the evenness of the paved asphalt course.

The following principles should be observed during pavement and, especially, compaction of the Stone Mastic Asphalt surface courses:

- **Pavement**

Thermally insulated vehicles should be used for delivering the asphalt mixture. If possible, a feeder should be used for paving Stone Mastic Asphalt surface courses in large construction lots.

The temperature of the asphalt mixture in the hopper of the road paver bucket should be evenly distributed and not fall below 150 °C (provided that no viscosity changing additives are applied). An „even temperature distribution" refers to, for example, no cold asphalt batches formed in corners or niches.

The operation paver should be set up in such a way that it achieves a proper pre-compaction depending on the paving speed. The utilization of high compaction equipment is not recommended. An air temperature of at least 5 °C (course thickness ≥ 3 cm) or at least 10 °C (course thickness < 3 cm) should be ensured during the paving operation.

The underlying course is to be mechanically sprayed with a polymer-modified bitumen emulsion C60BP4-S for load classes LC100 to LC3.2 and with a solvent-containing bitumen emulsion C40B5-S for load classes LC1.8 to LC0.3. The dosing amount should be aligned with the type and properties of the course.

• Compaction

Generally, roller compaction should commence as early as possible, i.e. compaction should be executed close to paver. The constantly uniform asphalt mixture temperature, which complies with the requirements, is the essential prerequisite. The appropriate temperature of the Stone Mastic Asphalt surface course immediately behind the paving screed is between 140 °C and 150 °C for not temperature-reduced asphalt mixtures.

The number of rollers required can be estimated as follows: one roller per every two metres of paving screed width. An application of minimum of two rollers should be planned. Roller compaction should be executed with tandem rollers/vibration rollers (operational weight > 7 t). Compaction under vibration should only be executed at sufficiently high mixture temperatures and after static pre-compaction. In case of a rigid substrate (e.g. concrete or paving stones) or course thicknesses under 2 cm, no vibration should normally be executed, since this could lead to loosening and crushing of aggregates.

On hot days (meteorological definition: air temperature > 30 °C), special care is required during pavement of Stone Mastic Asphalt surface courses. The development of the surface appearance should be continuously observed until the application of the gritting material.

In order to reduce the risk of bitumen flushing to the surface, it is advisable to delay the compaction process allowing the course to cool down and, if applicable, to set a lower production temperature for subsequent deliveries of the asphalt mixture.

On hot days, the final compaction state can be achieved with significantly less compaction energy due to the slow cooling of the course.

• Additional information/supplements

Any necessary supplementary manual paving of Stone Mastic Asphalt surface courses should be executed quickly, without delays and, if possible, simultaneously with the paving executed by the paver. Roller compaction should take place immediately after paving. The lack of pre-compaction by the paver is to be compensated by a correspondingly higher course thickness. Insufficient mixing time and/or unsuitable stabilizing additives can result in ineffective stabilization. This can lead to a mortar accumulation and patchy, „overgreased" Stone Mastic Asphalt surface areas. A mixing time necessary for dissolving should be as much observed as the use of high-quality fibers and/or fiber pellets.

Special attention should be paid to creating seams and joints.

C.2.2 Surface treatment/traffic release/quality control

Initial skid resistance of the Stone Mastic Asphalt wearing course can be increased by gritting, blunting measures should Chippings size of 1/3 mm with aggregates with the crushed aggregate surface ratio of $C_{90/1}$ has proven to be mostly effective. The quantity of the gritting material usually amounts to 0.5 to 1.0 kg/m².

The gritting material should be applied onto the sufficiently hot surface as early as possible in order to ensure its permanent integration into the course.

The main compaction procedure should not, however, be impaired. Roller-mounted spreaders have proven to be suitable to reach a uniform surface appearance.

To ensure a stable pavement process, accompanying measurements of the compaction quality should be made. The currently referenced volumetric densities in Marshall specimen are required to representatively perform the absolute measurements.

After the completion of paving and compaction, a sufficient time should be allowed for the cooling down of the asphalt surface course prior to traffic release. The prescribed minimum of 24 hours and/or 36 hours, if the surface course has been paved on a hot course underneath it, can be too short during high summer temperatures. The Stone Mastic Asphalt surface course should be cooled down below 20 °C prior to traffic release. Driving over a too early released surface course can lead to mortar accumulation on the surface and, therefore, loss of the skid resistance and deformations.

C.3 Noise-reducing asphalt surface courses

C.3.1 Pavement and compaction

The operations of mixing, transportation and paving should be coordinated. A well-organized construction sequence can, on one hand, largely prevent unnecessary queuing time of the transport vehicles with associated losses of the asphalt mixture temperature and, on the other hand, avoid a downtime of the paver that may result in problems with compaction and longitudinal evenness. A continuous feeding of the paver with the asphalt mixture of the permanent temperature is an important prerequisite for the uniformity of texture and compaction as well as for the evenness of the paved asphalt course.

The following principles should be observed during pavement and compaction of the Stone Mastic Asphalt noise-reducing surface courses:

• Pavement

If there is no previous experience with this type of asphalt, it is recommended to carry out trials at the mixing plant and to pave a test section. A feeder should be used for paving broad sections or in large construction lots.

Conventional asphalt binder courses should not be used as underlying courses. It is recommended to apply a dense asphalt binder such as SMA16 which has shown excellent results. The underlying course is to be mechanically sprayed with a polymer-modified bitumen emulsion C60BP4-S at a dosing rate of 350 to 450 g/m².

The operation paver should be set up in such a way that a uniformity of the paved course is reached over the entire pavement width. Should the paving screed be equipped with a high compaction mode, such mode should not be activated. The temperature of the delivered asphalt mixture should not fall below 140 °C when using bitumen grades 40/100-65 A or 25/55-55 A, unless temperature-reduced asphalt mixture is applied. An air temperature of at least 10 °C and the underlying course temperature of at least 8 °C should be ensured during the paving operation (paving during strong wind should be avoided).

• Compaction

The roller compaction should commence right behind the paver. It should be executed with smooth drum rollers of a total weight between 6 t and 13 t. Since SMA plus demonstrates a high resistance to compaction, special care should be taken to compact in short roller path lengths. Strict requirements related to noise-reduction concerns apply to the evenness of the SMA plus asphalt surface courses.

Hint: Oscillating compaction and/or light vibration compaction with low amplitude have proven to be effective. A purely static compaction may not reliably achieve the required minimum compaction degree of 97.0 %. Damages to the aggregate structure caused by vibratory compaction should be avoided.

Care should be taken to ensure the levelling of the underlying course during maintenance. Either the course should be renewed or a levelled out by fine milling.

Gritting should not be applied. The guideline values for the void content in the Marshall specimen for SMA plus surface courses lie between 9.0 % and 14.0 % by volume. The void content of the paved course should lie between 10.0 % and 15.0 % by volume.

- **Paving thickness and amount**

Target course thicknesses of 3.5 to 4 cm for SMA 8 plus and 2.5 to 3 cm for SMA 5 plus have proven to be most suitable.

C.3.2 Surface treatment/traffic release/quality control

Gritting measures should not be taken to provide the initial skid resistance of SMA plus wearing courses.

After the completion of paving and compaction, a sufficient time should be allowed for cooling down of the asphalt surface course prior to traffic release. The prescribed minimum of 24 hours and/or 36 hours, if the surface course has been paved on a hot course underneath it, can be too short during high summer temperatures. The Stone Mastic Asphalt noise-reducing surface course should be cooled down below 20 °C prior to traffic release. Driving over a prematurely released surface course can lead to mortar accumulation on the surface and, therefore, loss of the skid resistance and deformations.

Compaction tests (non-destructive) during the construction stage are possible for Stone Mastic Asphalt noise-reducing surface courses (SMA plus) as well and are expressly recommended, although not considered suitable for assessing the requirements set forth in the construction agreement.

C.4 Asphalt binder courses

C.4.1 Pavement and compaction

The operations of mixing, transportation and paving should be coordinated. A well-organized construction sequence can, on one hand, largely prevent unnecessary queuing time of the transport vehicles with associated losses of the asphalt mixture temperature and, on the other hand, avoid a downtime of the paver that may result in problems with compaction and longitudinal evenness. A continuous feeding of the paver with the asphalt mixture of the permanent temperature is an important prerequisite for the uniformity of texture and compaction as well as for the evenness of the paved asphalt course.

The following principles should be observed during pavement and compaction:

• Pavement

The pavement of the SMA binder course does not differ from the paving of conventional asphalt binder courses. A feeder should be used for paving broad sections or in large construction lots. An asphalt mixture temperature between 150 °C and 170 °C, depending on the bitumen viscosity, should be kept.

An air temperature of at least 0 °C should be ensured during the paving operation. The underlying course is to be covered with a polymer-modified or with a solvent-containing bitumen emulsion. Spraying the bitumen emulsion C40B5-S on the milled surface areas can be advantageous prior to applying a polymer-modified bitumen emulsion.

• Compaction

The compaction should be performed with tandem vibration rollers (operational weight of 7 t to 10 t). It should be executed in a static and dynamic modus without causing the crushing of aggregates. SMA binder course can be generally described as easily compactable, if designed accordingly. Should SMA binder course be paved with its minimum thickness of 6.0 cm, a medium or even small vibration amplitude has proven to be effective. Combination or pneumatic-tyred rollers can be operated directly behind the paver for particularly closed surface textures or with regard to a temporary traffic.

Hint: In addition to a moderate vibration application, using pneumatic-tyred rollers has proven suitable in generating a dense surface texture, when subsequently covered by mastic asphalt in order to prevent blistering.

• Paving thickness and amount

Due to the high proportion of coarse aggregates, which characterizes SMA binder course, the course thickness should not fall under 7 cm. For thicknesses over 10 cm, a SMA binder course with a maximum aggregate fraction size of 22 mm should be considered.

C.4.2 Traffic release/quality control

Stone Mastic Asphalt binder courses should only be gritted, if intended for temporary traffic at the high speed.

Stone Mastic Asphalt binder courses are characterized by an increased bitumen content. This can have a negative effect on the deformation behaviour if traffic release is premature. The required cooling time of at least 24 hours should be strictly adhered to. The Stone Mastic Asphalt binder course should be cooled down below 20 °C prior to traffic release to allow the formation of the viscous bitumen structure.

The SMA B C asphalt binder course should therefore have cooled down to below 20 °C once before it is released for traffic movement, so that the viscous structure of the bitumen can be formed.

Compaction tests (non-destructive) during the construction stage are recommended for Stone Mastic Asphalt binder courses as well, although not considered suitable for assessing the requirements set forth in the construction agreement. The partially rough surface structure can impact the measurement values and requires experienced construction material staff.

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Dipl.-Ing. (FH) Thomas Behle, Hohenloher Asphalt-Mischwerke GmbH & Co. KG: Figure 11

Fliegl Bau- und Kommunaltechnik GmbH: Figure 12

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