HEAVY DUTY SURFACES
THE ARGUMENTS FOR SMA

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CONTENTS

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SUMMARY

Stone Mastic Asphalt (SMA) has become a popular asphalt mixture for the surfacing of heavily trafficked roads, airfields, industrial and harbour areas in Europe and its use is spreading across the world. The even surface that can be obtained using SMA provides comfortable riding characteristics whilst its texture gives good skid resistance with relatively low traffic noise. The strong aggregate structure provided by the coarse aggregate particles gives excellent resistance to permanent deformation and the binder rich mastic, which fills the voids between those particles, makes SMA highly durable respectively sustainable. Due to the high binder content a drainage inhibitor is needed to prevent binder drainage. Modified bitumen can be used to further enhance the mechanical properties of SMA. The specific mixture composition allows thin layer application, which means that less of this high quality asphalt needs to be used in the surface course of pavement construction. As a result SMA has proved to be cost effective even though it requires a higher binder content and the use of high quality aggregates. A well designed SMA requires extremely low maintenance when applied in a properly designed construction. The additional advantages of quick application, and ease of use in maintenance operations can contribute to lower life cycle costs.

Longer service life, thinner construction and reduced noise levels impart sustainable and environmental benefits.

The European standard for SMA was published as EN 13108-5 (Stone Mastic Asphalt) and many European countries have also their national application document for SMA. In the USA and India, where SMA is called Stone Matrix Asphalt, and elsewhere in the world, its use is increasing in popularity amongst road authorities and the asphalt industry.

This report covers all the above points and highlights the key areas that must be satisfied to ensure success when producing and laying SMA. It is envisaged that it will be of use to producers, layers, contractors, consultants and suppliers alike.


Germany


United Kingdom


Netherlands


Slovenia

Turkey


Norway


Hungary


Denmark

1. INTRODUCTION

In many countries Stone Mastic Asphalt (SMA) is a very attractive asphalt for surface and binder courses of highways, roads, airports, harbours and other pavements. SMA possesses important functional, economic and technical advantages compared to conventional mixtures for asphalt courses: providing excellent riding characteristics; combining high stability with high durability and is capable of being applied in thin layers. The environmental benefits of its quieter surface have also been recognised.

SMA was developed in Germany in the mid-1960s and proved to be extremely effective to withstand wear and resisting damage from studded tyres. In recognition of its excellent performance a national standard was set in 1984. Since then it has spread throughout Europe and across the world.

As countries gained experience with SMA they have found that to achieve the optimum performance from this excellent material the mixture has to be well designed and a high standard of production and contracting has to be maintained. The area of SMA laid in Europe, and as a percentage of asphalt production, is set out by country in Table 1.

CEN published the European Standard for Stone Mastic Asphalt (EN 13108-5) in 2006 and an amendment in June 2008. This standard specifies a technical framework which allows the publication of national application documents in each country. A description is given in Annexe D.

This status report provides a survey of the use of SMA in a number of European and worldwide countries and EAPA expects that it will be of assistance to road authorities, asphalt contractors and asphalt producers who are looking for methods to further increase the life of asphalt pavements.

Country	% of total annual hot & warm mix asphalt production 2016
Austria	6,0
Belgium	14,2
Croatia	3,2
Czech Republic	6,2
Denmark	13,0
Estonia	2,3
Finland	11,8
Germany	9,0
Hungary	5,5
Lithuania	5,0
Netherlands	10,0
Slovakia	4,5
Slovenia	6,0
Spain	1,2
Turkey	4,0

Table 1:
Use of SMA in Europe as percentage of hot and warm asphalt production [EAPA – Asphalt and Figures 2016]

2. FUNCTIONAL PAVEMENT CHARACTERISTICS

The main considerations when choosing a type of asphalt for the surface course are the functional characteristics provided by the materials in relation to the life-cycle costs of the pavement.

The main functional characteristics of SMA are:

- Skid resistance, evenness (transverse and longitudinal), visibility and aquaplaning
- Resistance to permanent deformation (pavement performance) and durability
- Noise reducing surface

SKID RESISTANCE

SMA can be designed to achieve the levels of skid resistance required on most road applications. The skid resistance achieved will depend on two principal factors:

- Selection of aggregate type
- Design of surface texture

Coarse aggregate with a Polished Stone Value appropriate to the site should always be used. Higher PSV aggregates will resist polishing under traffic, and ensure maintained skid resistance for a longer period. Regulations exist in most countries concerning acceptable PSV levels, determined by local aggregate availability and experience of use. Various studies have indicated that the performance of SMA will be equal to or better than that of conventional asphalts with the same aggregate. Surface texture is important in both the dispersal of surface water at the tyre/road interface and in the provision of grip through the penetration of tyre rubber into surface depressions. It is possible to design different levels of texture into SMA surfaces. This design is a factor of both aggregate size and of the degree of mortar filling of the voids. Larger aggregates will give a good texture depth, the smaller sizes rather less. It is thus possible through mix selection and design to meet the surface texture regulations for high speed and low speed traffic in most countries. In design it is also important to ensure that mixes are not overfilled with mastic as this can result in loss of skid resistance and texture under traffic.

SMA mixes, when new, have a rather thicker binder film on the surface than most other conventional asphalt types. In the past this lead to concerns in some countries that initial skid resistance during the first few weeks of trafficking may be lower than expected. European studies showed that SMA offers a sufficient skid resistance at this initial stage. In several countries it is common practice to apply a surface treatment with gritting material e.g. aggregates of 1 - 3 mm to the surface during the final passes of compaction to obtain a good skid resistance value in the initial stage.

VISIBILITY/AQUAPLANING

The high surface texture of some SMAs compared to low surface texture asphalt concrete means that more water can be stored in the surface. Next to this the textured surface provides reduced glare at night from the reflection of lights of oncoming vehicles, increased visibility of road markings, and reduced splash and spray.

STABILITY

Because of its strong aggregate structure (stone-to-stone skeleton), the initial evenness of the finished surface provided by the paver determines the riding quality of the pavement to a greater extent than in the case with asphalt concrete, so additional compaction by the roller is limited. As a result even higher comfort levels for the driver can be achieved when compared to those already provided by other asphalt surfacing. Due to SMA's high resistance to permanent deformation this initial evenness remains largely unaltered, both in the longitudinal and transverse direction (although the longitudinal evenness is mainly dependent on the bearing capacity of the lower pavement construction). This means that SMA has a high resistance to rutting/ permanent deformation.

DURABILITY

The original reason for developing SMA was the need to improve the resistance to permanent deformation of pavement surfaces and to wear from studded tyres. This goal was achieved and SMA has proved to be a very durable, wear-resistant material. It was found that stripping, surface cracking (temperature and traffic induced) and ravelling are failure mechanisms that do not tend to be relevant to SMA. The excellent durability of SMA derives from the impervious nature of the mastic mortar. The mortar is very binder-rich and consequently the rate of deterioration of the binder is extremely low.

The first SMA surface courses were built in the mid-sixties. Some of them, due to thick binder films in SMA lasted without maintenance for more than 30 years. The SMA concept started in other countries from the mid-eighties and early nineties, and the same excellent performance has been experienced.

NOISE

Noise level reductions reported from several countries are given in Table 2 (negative values indicate a noise level increase). As can be seen from Table 2, the noise level from SMA must be judged against the standard alternative in the country of use. In situations where high textured surfaces are used to ensure certain friction characteristics (e.g. HRA, brushed cement concrete) SMA will prove to be much quieter at the same texture level. In comparison with smoother and lower textured asphalt concretes the noise reduction will be more limited, although of course the SMA texture will generally be greater. The application of grit to improve friction will increase the noise level for a short period, possibly over few months.

Country	SMA type	Reported reduction dB (A)	Reference
Germany[a] **V = 50 km/h**	8	+ 2.0 to - 2.0[b]	AC 11
Netherlands **V = 60 – 100 km/h**	8 11	+ 0.2 to + 0.6 0.0 to – 2.0[b] + 0.8 to – 0.5 + 1.0 to – 3.0[b]	AC 16
United Kingdom **V = 70 – 90 km/h**	6 10 14	+ 5.3 to + 5.2 + 3.5 to + 3.2 + 2.7	HRA 14

a) Calculation values
b) When the surface is treated with uncoated chippings > 2 mm

Table 2: Noise levels of SMA compared to other mixture types (Negative values indicate an increase in noise level)

RECYCLING

SMA is 100% recyclable in ex-situ processes. Material is excavated from the road and transported to processing units in order to be used as an ingredient in fresh asphalt mixtures. Excavated material is mainly known as RAP (Reclaimed Asphalt Pavement) or RA (Reclaimed Asphalt). The use of recycled material in SMA is not recommended, due to the need for an accurate control of the grading, and the requirement to use high quality aggregate and suitable RA management.

SUMMARY

The main advantages of a sustainable SMA layer are:

- Surface characteristics giving a safe and comfortable ride
  - high friction level
  - improved evenness/resistance to rutting
  - reduced noise level (under certain conditions)
  - improved visibility characteristics in wet weather

- Durability
  - increased resistance to surface deterioration giving a longer service life
  - reduced need for maintenance/lower Life Cycle costs

- Speed of maintenance
  - the relatively thin layer construction means that it can be planed and replaced easily
  - less disruption to traffic during maintenance.

For decades SMA pavements have proven to perform better than other pavements in practice when comparing mechanical characteristics and durability. Excellent performance requires optimum pavement and mixture design as well as quality laying.

SMA roads properly designed and constructed will last twice as long as conventional asphalt so 100% of the virgin material which would have been used to reconstruct it will be preserved.

3. SMA FOR HEAVY DUTY PAVEMENTS

SMA has been successfully used in heavy duty pavements across Europe. To ensure success the following conditions should be observed:

- Given the same load on the pavement, the contact pressure between the particles in SMA is greater than in AC, so the possibility of abrasion increases. In the case of heavy duty pavements (heavily trafficked roads, industrial sites etc.) this requires a high quality aggregate (abrasion resistance, particle shape) and, as this effect is especially significant during compaction, the compaction procedure should be adapted (avoidance of overrolling, no vibrating rolling).

- For heavy duty pavements it is not only the SMA mixture that needs to be carefully designed; the layer thickness also requires careful selection. The applied layer thickness of SMA has a close relation to the aggregate size. The selection of the thickness is even more important if high contact pressures occur. The (nominal) layer thickness should be at least 2.5 x nominal aggregate size. Based on long term practical experiences for new construction maximum layer thicknesses have been reported to be between 20 mm for a SMA 6 (e.g. Netherlands), to 50 mm for a SMA 16 (e.g. Sweden). For heavy duty pavements a reduction of at least 5 mm is often applied to these figures.

- In the road sufficient friction between the surface layer and the second layer is required; no sliding plane should occur (which might be the case e.g. when applying a Stress Absorbing Membrane Interlayer [SAMI]).

- The failure risks related to overfilling the aggregate structure, insufficient stability of the aggregate structure or the large number of degrees of freedom for displacement of the aggregate particles is reduced by using a binder with a relatively high viscosity at performance temperatures (e.g. polymer modified bitumen according to EN 14023 Standard for Polymer Modified Binder).

- The selection of the sand is a balance between stability and workability, and this also determines the percentage of crushed rock fines.

- In cases where the intrinsic resistance to permanent deformation is not sufficient, an increase in resistance can be obtained by using a modified binder, e.g. in Germany, Netherlands and in the Nordic countries good results have been obtained with standard bitumen as well.

- To obtain effective reduction in rutting, the underlying asphalt courses (binder courses and/or base courses) of the total construction must have sufficient resistance to permanent deformation.

- In many European countries modified binders are used for SMA for heavy duty pavements.

4. THE PRACTICE OF SMA IN EUROPE AND COUNTRIES ACROSS

In Annexe C the practice of using SMA in Europe and countries across is described. From this overview the following trends can be distinguished:

- All countries report very positive experiences with SMA, especially its surface characteristics, durability, riding comfort and sustainability. Its performance on heavy duty pavements is excellent and on lower volume roads, the service life of SMA compares favourably. These excellent experiences are obtained when the technological requirements of SMA are fully met.

- The major SMA types are SMA 8, SMA 11 and SMA 16. There are national preferences due to the different aggregate grading's used. As a result; Germany and the Netherlands uses SMA 6, SMA 8 and SMA 11; Sweden SMA 4, SMA 8, SMA 11 and SMA 16; and the United Kingdom SMA 6, SMA 10 and SMA 14. The Nordic countries use SMA 16 to give increased resistance to studded tyres.

- Generally, crushed aggregates are recommended for both the coarse and fine mineral fractions though for the fine fractions partly uncrushed aggregate (natural sand) is sometimes used. For heavy duty applications there is a move towards higher quality aggregate: all crushed aggregates, only crushed rock, coarse aggregates with a lower flakiness index.

- Type of Binder: Polymer modified bitumen (e.g. 25/55-55) and standard bitumen (e.g. 50/70) is chosen, on lower traffic volume roads standard bitumen.

- The balanced technological concept of SMA requires virgin aggregates and for all aggregate sizes a constant level of oversize and undersize.

- For the mixture composition, the allowed percentage of aggregate passing sieve 2 mm and binder contents vary according to Table 3. (Note: data "translated" to CEN-sieve series). The table summarises the ranges in target compositions, based on different experiences throughout Europe.

SMA Type	**Percentage passing sieve 63 µm**	**Percentage passing sieve 2 mm**	**Binder content, %**	
			On 100% aggregate	**"in" mixture**
5 – 6	6 – 12	27 – 40	5.6 – 8.0	5.3 – 7.4
8	6 – 12	20 – 35	6.5 – 7.5	6.1 – 7.0
9.5 – 10	6 – 11	21 – 32	5.3 – 6.8	5.0 – 6.4
11 – 12	6 – 11	18 – 32	5.3 – 7.5	5.0 – 7.0
14	6 – 11	15 – 30	6.5	6.1
16	5 – 10	15 – 30	6.4	6.0

Table 3: Variation in mixture composition requirements

Note: Controlling the grading viz. the "gap in the grading" could be improved by using control sieves at the lower and upper side of the gap. Viz. for SMA 8 that could be ISO-sieves 2.8 mm and 4.0 mm; for SMA 11, sieves 2.8 mm and 5.6 mm.

- The mixture design is generally based on the volumetric properties of impact compacted specimens (Marshall compaction). Denmark has requirements for VMA, VFB and Vs ("voids in the mineral aggregate", "voids filled with binder" and "voids in the specimen" respectively). Other countries have only specifications for Vs. The variation in the requirements for the latter are given in Table 4. It should be indicated that the basis for the voids calculation might be different for different countries.

SMA Type	Vs (%)[a]
5 – 6 8 9.5 – 10 11 – 12 14 16	2 – 4 2 – 5 3 – 6 1 – 5 2 – 5 2 - 5

a) Voids in the specimen

Table 4: Variation in the volumetric mixture design requirements

• Several countries have additional mechanical requirements, varying from Marshall properties to structural (performance) based.

• Advised layer thickness varies. General experience shows that Heavy Duty Pavements (HDP) applications require relatively thin layers.

• In general the requirements for the mixture in the road allow higher void contents, generally between 2 and 6%. Some countries require a specific degree of compaction (e.g. Germany ≥ 98%). A comparison with these values is not possible at present due to the differences in establishing the reference density. EN 13108-20 suggests the number of gyrations to use for compaction to compare with the Marshall/ impact compaction.

The reasoning behind the differences between countries can be found in the climate and higher legal maximum axle weights. In the Northern part of Europe (wet and cold regions) lower voids and higher bitumen content is used (often requiring both modified bitumen and drainage inhibitor), whilst in the drier and warmer regions the void content is relatively higher and the binder content lower with a stiffer binder. These percentages might be theoretical as voids below 3% are considered to be risky, due to potential problems with stability. Generally 4% to 6% after laying is considered to be 'normal'.

DRAINAGE INHIBITORS

Due to the thick binder film required in SMA a drainage inhibitor (stabilizing additive) is necessary. In general fibers are used such as cellulose and specific organic materials. Most drainage inhibitors are active during the storage, transport and laying of hot SMA; after compaction they have no influence to the performance of the mixture. However, some proprietary inhibitors have been found to give improved resistance to permanent deformation at higher temperatures, reduced ageing of the bitumen, increased fatigue strength and further increases in durability giving longer service life. Cellulose fibers are added mostly in pelletised form and dosed (automatically or manually) in the mixer through a pipe to give better distribution and sometimes reduced mixing time.

The required amount of inhibitor is based on practical experience. However, in the Netherlands a test method for measuring the drainage inhibiting capacity of several materials has been developed and the binder drainage test (EN 12697-18) according to Schellenberg has been found to give good results.

MODIFIED BINDERS

Modified binders include e.g. polymers such as SBS and EVA, waxes or rubber powder.

Modified binders are used in SMAs for several reasons:

- to increase the resistance to permanent deformation
- to increase the life time of the pavement surface
- to reduce application and damage risks especially in cases of very thin layers
- to reduce the need for a drainage inhibitor (though this can still be necessary with some PMBs).

MIXTURE DESIGN

Starting from defined grading envelopes and binder limits, the mixture designer adjusts the required mixture composition to achieve the required volumetric properties. Specimens are generally prepared by impact compaction (Marshall hammer). However, a number of countries report that the impact compactor does not provide realistic specimen densities compared to those obtained in the road. In Denmark and the Netherlands, it has been found that the slab compactor and/ or the gyratory compactor give much more realistic density results.

The essential characteristics of the SMA concept are the volumetric parameters: the quality of the mixture is essentially determined by the right volumetric proportion of the constituent materials viz. the right distribution of skeleton voids (VCA) and mastic portions. A higher void content in the aggregate structure can be achieved by constructing a larger gap in the aggregate grading - lowering the grading curve at the lower end of the coarse aggregate section.

5. CURRENT DEVELOPMENTS

SMA BINDER COURSES (SMA B C)

SMA is a well-known asphalt concept in Europe and in many countries and continues to be developed worldwide. Some of the areas of developments are commented in this section.

SMA type mixtures are being developed for use in layers other than surface courses. The main advantages of SMA are it's high-quality surface characteristics and durability in combination with its excellent resistance to permanent deformation and crack resistance. In binder courses surface characteristics are not relevant. Binder courses have to be rut resistant with excellent fatigue behaviour. Furthermore, the binder course must be impermeable.

In recent years binder courses with high deformation resistance and low voids were used. Durability was attained with hard bitumen and low bitumen contents which yielded relatively high void contents. These binder courses are susceptible to water ingress and when renewing the road surface the binder courses often showed considerable damages.

In the binder course traffic induces especially high shear stresses which often lead to permanent deformations. The highest shear stresses will generally occur about 20 – 70 mm below the surface course(see Figure 1). In some climates the maximum deformation can be located at a shallower depth.

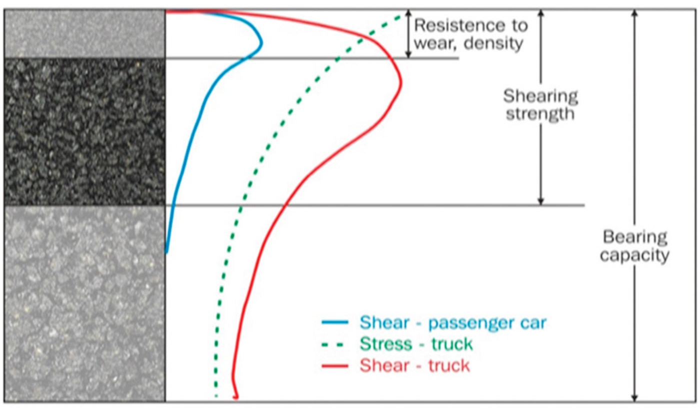

Figure1: Asphalt Pavement - Shear and Stress distribution in pavement due to loadings

Practical experiences in Sweden and Germany show that binder courses based on the SMA concept are a promising solution to provide all required properties (stable, durable and versatile) for a highly stressed binder course. Paving and compaction of a SMA B C is done with standard paving equipment, a material transfer vehicle (MTV) can assist to achieve no stops and starts (see Figure 2). In Germany the characteristics for SMA binder courses are given in Table 5, with aggregate size 22 mm and 16 mm. SMA binder courses contain a binder content of 4.8% - 5.2% and reclaimed asphalt (RA) up to 30%.

Characteristics of Layer		SMA 22 B C	SMA 16 B C
Paving thickness	cm	9.5 – 12.0	6.0 – 9.5
Compaction degree	%	≥ 98	≥ 98
Void content (core drill)	Vol.-%	1.5 – 5.5	

Table 5, Characteristics of SMA Binder Course, Extract of H Al ABi, FGSV, Germany, 2015

SMA binder courses can temporarily be used as a surface layer and especially under noise reducing surfaces and due to its low void content.

Figure 2, Laying of a SMA binder course

NOISE-REDUCING SMA (SMA NR)

Tyre/road surface interaction noise can be significantly reduced by laying appropriate pavements. Thus, attempts have been made for quite some time to develop additional surface types that would reduce noise or improve existing asphalt surfaces. The SMA mixture design with improved noise reduction (SMA NR – in German SMA LA (Lärmarm)).
has been successfully applied e.g. in Austria, Denmark and Germany. These designs differ in terms of particle size distribution, maximum aggregate size and binder volume. The aggregate composition leads to higher voids, which provides good noise reducing results together with the optimised surface texture. The German characteristics of SMA with noise reducing properties (see Table 6) need just minor adjustments compared to standard SMA surface courses and is easier to produce, lay and compact than PA.

Characteristics of Layer		SMA 8 S (NR)	SMA 5 S (NR)
Paving thickness	**cm**	2.5 – 4.0	2.0 – 3.0
Compaction degree	**%**	≥ 97	≥ 97
Void content	**Vol.-%**	9.0 – 14.0	9.0 – 14.0
Evenness (4 m section of measurements)	**mm**	≤ 3.0	≤ 3.0

Table 6, Characteristics of Noise Reducing SMA, Extract of E LA D, FGSV, Germany, 2014

The only difference to standard SMA is that SMA with noise reducing properties cannot be gritted due to the open structure and the higher voids (see Figure 3 and 4).


Figure 3 and 4, Noise Reducing SMA, Surface Texture

To date, SMA with noise reducing properties has been used with convincing results regarding performance and noise reducing properties e.g. of more than 4 dB(A) in Germany. A good alternative when it comes to noise reduction and durability (see Table 7).

		High quality crushed aggregates, crushed sand, mineral filler[1]
Aggregate size < 0.063 mm	% by weight	6 – 8
Aggregate size > 2.0 mm	% by weight	80 – 85
Aggregate size > 5.6 mm	% by weight	70 – 80
Aggregate size > 8.0 mm	% by weight	≤ 10
PSV		≥ 51
Bitumen type		40/100-65 A
Bitumen content (factor α)*	% by weight	B_{min} 6.6
Stabilizing additive		Cellulose fibers
Content	% by weight	≥ 0.3

[1] Usage of limestone filler recommended
* Factor α considers the density of the aggregate mixture

Table 7, Mixture Composition Requirements of Noise Reducing SMA 8 LA, Extract of E LA D, FGSV, Germany, 2014

6. ENVIRONMENTAL BENEFITS

SMA offers substantial environmental benefits to the road user, and to the community at large. Both in the initial application and in the long term as SMA has many benefits, for example the possibility for thin layer construction combined with high durability.

Longer service life and lower maintenance provides a reduction in user delays and congestions (with their implications for higher levels of pollution). Furthermore, since the frequency of accidents is higher during maintenance operations, SMA is likely to prove to be a safer type of construction for both road user and maintenance workers.

Safety is further improved by the nature of the SMA surface. In wet weather conditions it can accommodate more water than many other surfaces, so the risk of aquaplaning is reduced. And because water is held within the texture, rather than on the surface, there is less surface spray. Additionally at night there is the benefit of fewer glares reflected from the road surface and better visibility of road markings.

The even SMA surface, with its high resistance to permanent deformation, also contributes to safer driving, as well as improving ride comfort and thereby reducing driver fatigue. Additionally, SMA surfaces generally offer comparatively low levels of traffic noise.

SMA is 100% recyclable. The use of recycled asphalt (RA) in SMA surface courses is not recommended due to the need for very accurate control of the grading and the requirement to use high quality aggregate. At this moment trial sections have been built using partly re-used SMA.

7. COST EFFECTIVENESS

The initial material costs per tonne can be higher than those of standard Asphalt Concrete (AC) due to the higher binder content, the need for high quality aggregates, the requirement for a drainage inhibitor and modified bitumen, and the reduced production capacity, if extra mixing time is required to incorporate the drainage inhibitor. Nevertheless, in practice SMA surfacing is found to be a cost effective answer when evaluated on the final life cycle cost of the pavement for the following reasons:

SMA can be applied in thinner layers compared to AC. Where 35-50 mm AC is applied a 25-35 mm SMA can be used. This means that to maintain the same construction thickness a part of the AC surface course thickness can be replaced by less expensive binder or base course material. So the difference between construction prices will be less than expected when comparing the price of SMA and AC.

Longer performance life than AC. Experiences from Europe have shown an average performance life of 20 years for SMA surface courses. A survey of EAPA (see Figure 5) have analysed the performance life of different asphalt mixtures:

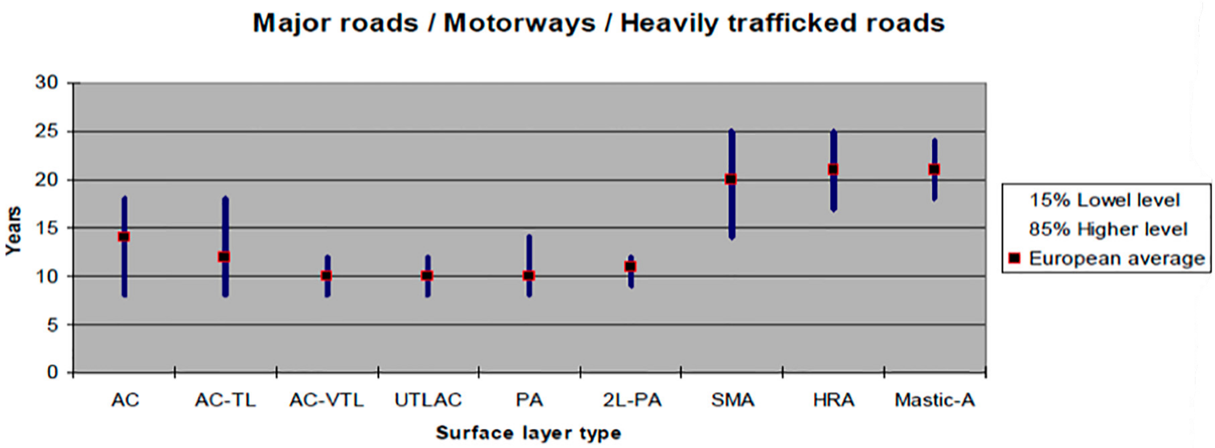

Figure 5: Durability of surface layers on major roads [Long-Life Pavements Technical Version, EAPA, 2007]

The cost of maintenance of the surface course is lower for SMA than for AC because of SMA's higher resistance to ravelling, cracking and wear, giving longer service life.

Due to the longer service life and reduced maintenance, the user delay costs are lower too. These costs can easily exceed the cost of the maintenance!

SMA can be used instead of less durable materials. For instance SMA 5 or SMA 6 is an alternative to surface dressing.

Individual projects should be evaluated to validate these advantages, but that is outside the scope of this report. An impression of the potential advantages of SMA can be gained by a simplified approach based on initial product costs. The theoretically required life span for SMA to obtain equal annual capital costs for SMA and AC surfacing at 5% interest level, is 25% longer, assuming the price of SMA laid as 120% of the price of AC per m^2.

Given that a life span increase of at least 5 - 10 years can be obtained, and that additional advantages covered earlier are gained, the choice of SMA can be a good investment.

8. CONCLUSIONS

SMA is a bituminous mixture that provides a various number of advantages compared to other asphalt mixes, specifically in the areas of surface performance, durability, sustainability and whole life cycle costs.

SMA has been successfully applied on heavy duty pavements as well as on lower volume roads, racing circuits, airports, harbours, etc. In all these application fields the main advantages are proven:

SMA is safe - superb riding characteristics as good skid resistance, evenness (transverse and longitudinal), good visibility and minimized aquaplaning.

SMA is durable - high resistance to permanent deformation (pavement performance) and to wear caused by traffic and climatic changes.

SMA is economical - less maintenance costs, convincing life-cycle costs leading to sustainable use of financial funds.

SMA is sustainable - 100% recyclable. In specific conditions SMA also provides a lower traffic noise level than alternative materials.

SMA´s longer service life gives it a better return on investment than most alternative asphalt mixtures even though the initial costs may be higher.

The limited differences in the national specification across Europe are a result of different climatic conditions, or legal maximum axle loads, and relate to voids, binder content and binder stiffness. In wet and cold regions, a lower void content and higher bitumen content is used whilst in drier and warmer regions the void content is generally higher and the binder content lower with a stiffer binder. However, aggregate grading remains fairly consistent other than in exceptional cases such as the resistance to studded tyres.

To gain the maximum benefit from SMA, it is important to ensure that the mixture is well designed and a high standard of production and laying is maintained. Then an economic and environmentally attractive solution will be obtained.

Longer road life, thinner construction (less use of aggregates respectively natural resources) and reduced noise levels impart sustainable environmental benefits.

Durability and sustainability of asphalt pavements are very important because of the increasing demands for availability of the road network which means that roads need be built to last for a very long time and the amount of maintenance required has to be reduced. Durability is not only important for the availability of the network, but it is also related to the effective use of material. Effective and efficient use of materials comes from better durability of products, which in turn leads to a lower environmental impact. SMA is one convincing asphalt concept to fulfil all the needs not just for heavy duty pavements today and in the future.

9. ACKNOWLEDGEMENTS

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ANNEXES

A. The Volumetric Characteristics of SMA

B. Production, Laying and Compaction

C. Practical Experience in Individual Countries

D. The European Standard for SMA

E. Bibliography/Abbreviations

ANNEXE A: THE VOLUMETRIC CHARACTERISTICS OF SMA

To achieve a long lasting SMA a good mix design is essential. The specific qualities of SMA can best be understood by looking at the volumetrics of the mixture.

SMA is a gap graded bituminous mixture with an aggregate skeleton, formed by relatively coarse aggregate particles, which is filled by a mastic of bitumen, filler and fine aggregate (sand), see Figures 1 and 2. Depending on the type of SMA the structure is built on aggregate with size 2-6 mm; 4-8 mm; 6-11 mm or 8-16mm. The mastic is a filler-sand mixture which is overfilled with binder hence the need for a drainage inhibitor (see Annexe B). The remaining void content in the final SMA mixture generally lies between 3 and 6% (by volume).

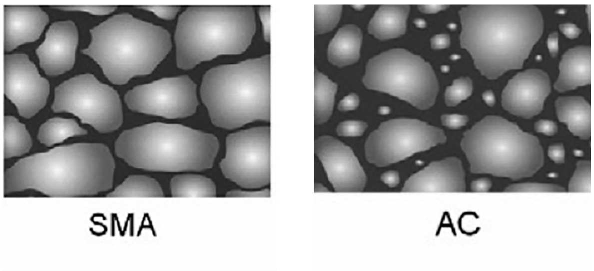


Figure 1, Stone Mastic Asphalt (left) and Asphalt Concrete (right)

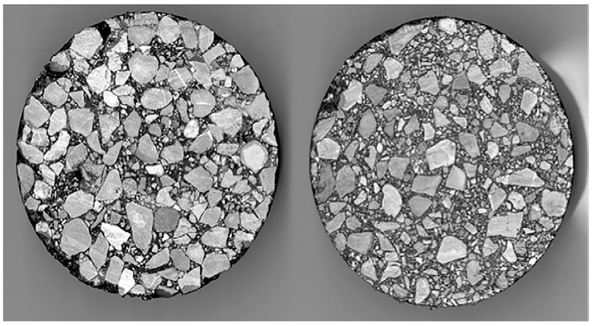


Figure 2, Drilled cores - Stone Mastic Asphalt (left) and Asphalt Concrete (right)

In continuously graded mixtures such as Asphalt Concrete (AC) the fine aggregate forms part of the aggregate structure. The remaining voids in such a structure are filled with a mortar, made up of very fine aggregate/filler and binder. To obtain a workable and durable AC mixture a kind of “gap” must exist. Generally this gap lies somewhere between 200 and 500 μm. The main aggregate structure is built by the aggregate which is larger than 500 μm/1 mm.

The principal difference between SMA and (continuously graded) asphalt concrete mixtures is that the gap in the grading curve is higher and wider, resulting in a significantly larger voids level in the aggregate structure. The gap approximately exists between 1 and 2 mm (SMA 6), 2 and 4 mm (SMA 8), 3 and 6 mm (SMA 11) or 3 and 8 mm (SMA 16). The coarse aggregate provides the structure, the fine aggregate is part of the mastic and has in principle no role in building the aggregate structure. See Figure 3 for a comparison of the grading curves of asphalt concrete and SMA according to the German specification.

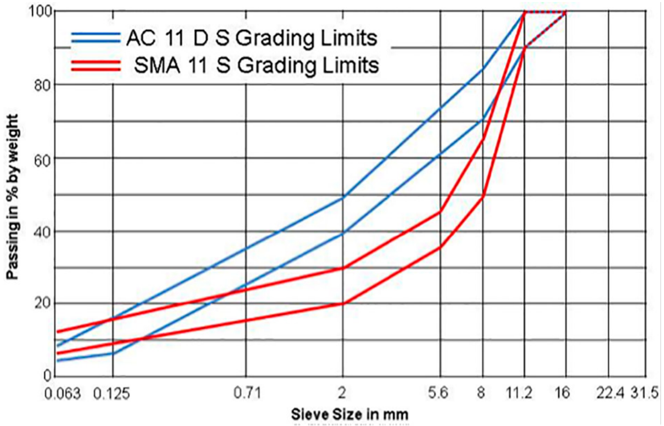


Figure 3, Grading curves, surface course AC 11 and SMA 11 (Germany)

From the volumetric point of view SMA is similar to porous asphalt which also consists of an aggregate structure built by coarse aggregate. In porous asphalt however the voids are only filled with a mastic to such a level that a void content of minimum 20% remains in the mixture; in the SMA aggregate structure the voids are filled to such a level that the remaining voids content in the asphalt mixture is approximately 3 to 6%.

The volume of voids in the compacted coarse aggregate should be greater than the mastic volume.

This has the following consequences.

- To obtain a stable aggregate structure the aggregate quality must be sufficiently high especially with regard to particle shape, viz. a low flakiness (see Figure 4a) and a high surface texture (see Figure 4b).
- Due to the large number of degrees of freedom for aggregate particle displacement, sufficient lateral support is required to provide the internal stability of SMA. This mechanism is significant both in the road and when testing. Tests without lateral support (as e.g. Marshall, uniaxial compression, bending tests, indirect tensile tests etc.) executed at relatively high temperatures are not suitable for this mixture, and wheel tracking and triaxial compression tests are recommended. In the case of heavy (static/concentrated) loading on the pavement the layer thickness must not be too large, see Figure 5.
- Excess of mortar may lead to fat spots in the road surface with a resulting loss of friction.

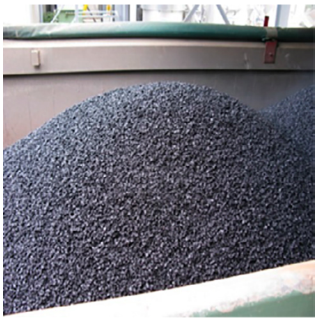
Figure 4a, Effect of aggregate flakiness

Figure 4b, Effect of aggregate shape

Figure 5, Effect of layer thickness

ANNEXE B: PRODUCTION, LAYING AND COMPACTION

During the production of SMA the right procedures should be followed as described in the Factory Production Control standard (EN 13108-21). SMA is produced and laid with standard equipment for hot mixed asphalt. However the production and laying processes for SMA require both specific care.



PRODUCTION

Batch plants and drum mixers can be used provided adequate attention is paid to aggregate supply control. As its specific performance is based on a strong gap graded aggregate composition, variations in the proportion of the “structural” and “filling” aggregate (viz. in the proportion coarse-fine aggregate) have an almost linear effect on the voids in the mixture. In principle this requires accurate control (consistency) of the amount of material passing/remaining on the sieves at the upper and lower side of the gap viz. a limited variation in the difference between the amounts of material on those sieves. In practice this means that the voids in SMA vary linearly with variation in the proportion of aggregate on the 2 mm sieve (whereas the voids in AC show a more limited effect of variation on this sieve). This requires a well-controlled production operation viz. the use of constituent aggregates with very limited grading variation. SMA is sensitive to overfilling of the aggregate structure with mastic. When such a overfill does occur, the mastic bears the loading. As an unmodified mastic has almost no deformation resistance this will result in a collapse of the aggregate structure leading to premature rutting.

Because of the rich mastic and the relatively low aggregate surface area the mastic may drain from the aggregate at low binder viscosity (at high mixture temperature, during storage, hauling and laying). For this reason, the viscosity of the mastic has to be increased and a drainage inhibitor, generally cellulose or other fibers, is normally incorporated.

The addition of the fibers can take place in several ways. Automatic dosing, which is preferred as it is not prone to operator error, incorporate pelletized or loose fibers.

If difficulty is found in achieving the correct air voids the following rule of thumb is recommended (SMA 11):

- To increase air voids, decrease the 4-8 mm material and increase the coarse fraction by the same amount. Do not change the fines.
- To reduce air voids, increase the 4-8 mm material and decrease the coarse fraction. Do not change the fines.
- Bitumen and mixture properties can be improved using certain additives, e.g. polymers. The use of modified bitumen is very common and can be justified in the case of severe conditions (climatic, traffic).

Before the start of the project a trial production of SMA is recommended.

LAYING

Laying by paver and compaction of SMA are relatively easy. Due to the strong aggregate structure, the contribution of the roller to the final compaction is limited. That means that the initial high evenness obtained by the paver will stay intact. The high pre-compaction achieved by the paver is useful. Thin layer application rolling requires specific attention, especially on a cold substrate when cooling will be rapid and early compaction essential. However too heavy rolling (e.g. with rollers which provide a high pressure like vibratory rollers) lead to aggregate crushing and is not recommended.

Due to the high internal cohesion of the mixture (provided by the high binder content, reinforced by applying a binder with increased viscosity) laying by hand is not recommended as it is difficult to obtain the optimum evenness, durability and density of the mixture.

COMPACTION

Adequate compaction is essential and has to be undertaken before SMA cools. The time available for compaction will depend on the properties of the mixture (particularly the binder), the layer thickness and the weather conditions. Sufficient rollers should be available for the job to complete the compaction everywhere in the time available to compact. The roller should follow the paver as close as possible.

For SMA surface courses only steel wheel rollers are selected. Based on long term experiences start with a static pass followed by one oscillating pass gives a satisfactory intermediate compaction, number of total passes depends on specified voids and density.

In general in a trial section it is verified that the produced SMA meets the mixture design, that the paving equipment lays down a satisfactory asphalt, and that the selected compaction equipment achieves the required/specified density. A good quality control system (QCS) during construction is recommended to monitor the relevant issues.

More detailed technical information concerning production, laying and compaction of SMA can be found in EAPA´s position paper The Ideal Project (2017).

ANNEXE C: PRACTICAL EXPERIENCES WITH SMA IN INDIVIDUAL COUNTRIES

1. CZECH REPUBLIC

C 1.1 APPLICATION

SMA has been widely used in the Czech Republic for about 20 years. SMA is applied as a wearing course on all new motorways. It is very often used for nearly all types of roads.

C 1.2 REQUIREMENTS

European standard - ČSN EN 13108-5 Stone Mastic Asphalt
Czech norm
ČSN 73 6121 Road building - Asphalt Pavement Courses - Construction and conformity assessment

There are different types of SMA. Requirements for 3 types which are most frequently used are shown in table 1.

SMA	**SMA 16 +**	**SMA 11 S**	**SMA 8 S**
Mineral aggregates	Crushed aggregate, crushed sand, manufactured filler		
Passing sieve in % by weight at			
22.4 mm	100		
16 mm	90 - 100	100	
11.2 mm	50 - 70	90 - 100	100
8 mm	35 - 60	45 - 60	90 - 100
4 mm	24 - 40	26 - 38	28 - 42
2 mm	18 - 28	20 - 28	20 - 30
0.125 mm	9 - 15	9 - 15	9 - 15
0.063 mm	7 - 11	8 - 12	8 - 12
Bitumen type	PMB 25/55-55,-60, -65 PMB 45/80 -50,-55,- 60 50/70	25/55-55 50/70	45/80-50 50/70 25/55-55
Minimum binder content % by weight Bmin	5.8	6.2	6.6
Void content (Marshall specimen) % by volume	2.5 - 4.5	3.0 - 4.5	3.0 - 4.5
Rutting resistance, WTSair (50°C, 5 000 – 10 000 cycles, in air)		0.07	0.07
Rutting resistance, PRDair (50°C, 5 000 cycles, in air)		5.0	5.0
Drainage test for mixture (Schellen-berg Test EN 12697-18) %	0.3	0.3	0.3

Table 1: Requirements for 3 most frequently used SMA types

High quality chippings only, Los Angeles (LA) category 25, resistance to polishing (PSV) of 50/53.

Requirements for drainage inhibitors; drainage test for mixture (Schellenberg Test EN 12697-18)
Use of drainage inhibitor 0,3 – 1,5 % by weight, cellulose fibers generally 0,3% by weight.

C 1.4. TYPE TESTING PROCEDURE
Marshall (specimen) 2x50 blows

C 1.5. SPECIFIC PRODUCTION & APPLICATION REQUIREMENTS:
Pneumatic rollers not permitted; compaction without vibration recommended.
Surface treatment (gritting) for enhanced initial skid resistance.

SMA	SMA 16 +	SMA 11 S	SMA 8 S
Layer thickness (cm):	4.0 – 6.0	3.5 – 4.5	2.5 – 4.0
Degree of compaction (%):	min. 96	min. 96 ∅ 98,0	min. 96 ∅ 98.0
Void content (Vol.-%):	2.0 – 7.5	2.0 – 7.0	2.0 – 7.0

C 1.6. PERFORMANCE IN PRACTICE
SMAs show generally a longer service-life than AC. That is why SMA is preferred.

2. DENMARK

C 2.1 APPLICATION

Since 1982 SMA wearing courses are used on high volume roads carrying a high proportion of heavy vehicles (e.g. motorways), industrial areas, airfields and other areas with high loading.

SMA 11 is the standard material. In situations with extremely high loading, SMA 16 is used. SMA 8 is used when thinner layers are preferred. Furthermore SMA 8 (and types with smaller aggregate size) is used as noise reducing pavement and to obtain lower rolling resistance of driving vehicles.

C 2.2 REQUIREMENTS

The types and composition of SMA refer to EN 13108-5 (see table below).

SMA		**SMA 8**	**SMA 11**	**SMA 16**
Bitumen	Medium traffic/load	40/60 or 70/100		
	High traffic/load	40/60 or use of PmB		
Grading				
Max size		8 mm	11.2 mm	16 mm
Passing, %				
22.4 mm		-	-	100
16 mm		-	100	90 - 100
11.2 mm		100	90 - 100	55 - 80
8 mm		90 - 100	40 - 65	-
5.6 mm		40 - 65	30 - 50	25 - 45
2 mm		22 - 35	20 - 30	15 - 25
0.063 mm		6.0 - 12.0	6.0 - 12.0	6.0 - 12.0

Table C 2.2 Requirements

C 2.3 SPECIFIC MATERIAL REQUIREMENTS

If polymer modified bitumen (PmB) is used, it has to be documented that the asphalt mixture with PmB has enhanced properties compared to the same asphalt mixture with standard bitumen.

The relevant properties/tests are:
Wheel Tracking Test according to EN 12697-22, procedure B at 50/60 °C.
Adhesion/cohesion: Determination of the water sensitivity of bituminous specimens at 25 °C according to EN 12697-12, method A or California Abrasion test supplemented with freeze/thaw.
Elasticity: Fatigue test, e.g. EN 12697-24, procedure E and determination of the elastic recovery at 10 °C according to EN 13398.

Mineral aggregates:
100% crushed material in all fractions. The fraction ≥ 2 mm shall be crushed material from quarries.

C 2.4 TYPE TESTING PROCEDURE

Type Testing is done according to EN 13108-20, validation model 6b, where all properties are demonstrated by product validation.

Volumetric properties, Marshall according to EN 12697-30 (2 x 50 blows).

The following requirements have to be met by all SMA specimens:

- Voids in Mineral Aggregate (VMA): ≥ 16.0%
- Voids in specimen (Vs): 2.0-5.0%
- Voids Filled with Bitumen (VFB): 77-92%

C 2.5 SPECIFIC PRODUCTION & APPLICATION REQUIREMENTS

SMA		SMA 8	SMA 11	SMA 16
Minimum application		50 kg/m²	70 kg/m²	90 kg/m²
Voids, % (v/v)	Tolerance $\overline{X} + (t * s)/\sqrt{n}$	≤ 8.0	≤ 7.0	≤ 7.0
Compaction, %	Tolerance $\overline{X} + (t * s)/\sqrt{n}$	≥ 95.0	≥ 95.0	≥ 95.0

$\overline{X}$ = average, t = statistic number, s = standard deviation, n = sample size.

The t-values are used in relation to tolerance calculations at a significance level.

C 2.6 PERFORMANCE IN PRACTICE

In Denmark SMA is designed with a low air void content and is expected to provide at least a 30% increase in service life compared to regular dense graded AC .

The experience with SMA is very good. Stripping and rutting problems have only been observed on a few occasions. If air voids are too high (e.g. in areas of hand work), there may be a risk of premature stripping, and if the proportion of fine aggregates is too high rutting may develop.

3. ESTONIA

C 3.1 APPLICATION

SMA is more widely used since the early 2000´s. First sections were built in the late 1990´s. Right now the oldest road sections are 15 years old. It is used for highways, national roads, municipality roads and bridges.

C 3.2 REQUIREMENTS

In Estonia SMA is produced according to EN 13108-5 and some choices regarding the aggregates, suitable binders, gradation and volumetric properties are mentioned in the Estonian standard "EVS 901-3 Tee-ehitus. Osa 3: Asfaltsegud" (EVS-EN 901-3 Road Construction, Part 3: Bituminous Mixtures).

Types and composition of SMA:

SMA 12		
Sieve	**Min in %**	**Max in %**
16 mm	100	100
12.5 mm	90	100
8 mm	40	650
6.3 mm	30	45
4 mm	25	36
2 mm	20	30
1 mm	16	25
0.5 mm	12	21
0.25 mm	10	18
0.125 mm	9	15
0.063 mm	8	12

SMA 16		
Sieve	**Min in %**	**Max in %**
20 mm	100	100
16 mm	90	100
12.5 mm	50	75
8 mm	25	42
6.3 mm	20	34
4 mm	17	29
2 mm	15	26
1 mm	13	23
0.5 mm	11	20
0.25 mm	10	18
0.125 mm	9	15
0.063 mm	8	12

C 3.3 SPECIFIC MATERIAL REQUIREMENTS

Mostly standard bitumen 70/100 (EN 12591) is used. If AADT is > 12.000, then PmBs (EN 14023) are used (grade 65/105-65, 75/130-65 or 75/130-75).
Aggregate properties depend on traffic volumes:
Los Angeles (LA) ranging from 20 to 15
Abrasion resistance of aggregate (Nordic Abrasion Test, AN) ranging from 14 to 7
Flakiness Index (FI) ranging from 15 to 10
Max fines content (f) 2%
Voids from 2-5%
Minimum binder content for SMA 12 is 6.2% and SMA 16 is 6.0%
Water sensitivity (ITSR) ≥ 90%
Abrasion resistance depends on traffic volumes from AbrA 36 to AbrA 24
Resistance to permanent deformation depends on traffic volumes from PRDAIR 13 to PRDAIR 7

In the recent years there is a trend from SMA 16 to SMA 12.

C 3.4 TYPE TESTING PROCEDURE

Binder content and gradation - EN 12697-1 and -2;
Volumetric properties (V, VMA, VFB) – EN 12697-5, -6 and -8;
Water sensitivity – EN 12697-12 and -23 (ITSR);
Abrasion resistance (Prall test method) – EN 12697-16;
Resistance against permanent deformation (Wheel Tracking Test) – EN 12697-22;
Void content @ 10 gyrations – EN 12697-31.

C 3.5 SPECIFIC PRODUCTION & APPLICATION REQUIREMENTS

Requirements have been set for the whole layer trying to avoid regulating the mixing and laying procedures and instead focus on end-results of the layer (thickness, density, evenness, friction). Existing requirements:

If special procedures or additives are not used to lower the mixing and compaction temperatures, then the lowest temperature where you can still place mixture into the paver is 130 °C for 70/100 standard bitumen.
Laying without paver is only allowed on extreme cases (hard to get places etc.). Engineer has to approve it.
Layer should meet the following requirements:
Void content 2-5% (on joints ≤ 8%)
Compaction degree ≥ 98% (ratio of reference density vs density of driller cores) (on joints ≥ 94%)

C 3.6 PERFORMANCE IN PRACTICE

SMA surface courses are considered to be a quite good solution for the local needs (studded winter tyres). SMAs are known to be more capricious than conventional AC surf mixtures. SMA is mainly used on high traffic volume roads (AADT above 6.000). SMA is used due to the fact that almost 70% of passenger vehicles have studded winter tyres (during winter), which causes rutting. Experiences showed that SMA has a better wear resistance compared to conventional AC mixtures.

4. GERMANY

C 4.1. APPLICATION

SMA is widely used in Germany since the mid 1960's, today SMAs are used for nearly all kind of roads. There are different types of SMAs in Germany, mainly used are SMA 5 S, SMA 8 S and SMA 11 S.

C 4.2. REQUIREMENTS

- German Technical Conditions of Delivery for Asphalt Mixtures for the Construction of Road Pavements (TL Asphalt-StB 07/13)
- German Additional Technical Conditions of Contract and Directives for the Construction of Road Asphalt Pavements (ZTV Asphalt-StB 07/13)
- German Additional Technical Conditions of Contract and Directives for the Constructional Maintenance of Road Asphalt Pavements (ZTV BEA-StB 09)

Types and required compositions:

SMA	**SMA 11 S***	**SMA 8 S**	**SMA 5 S**
Mineral aggregates	Crushed aggregate, crushed sand, manufactured filler		
Passing sieve in % by weight at			
16 mm	100		
11.2 mm	90 - 100	100	
8 mm	50 - 65	90 - 100	100
5.6 mm	35 - 45	35 - 55	90 - 100
2 mm	20 - 30	20 - 30	30 - 40
0.063 mm	8 - 12	8 - 12	7 - 12
Bitumen type	25/55-55 50/70	25/55-55 50/70	45/80-50 50/70 25/55-55
Minimum binder content **% by weight (factor α)***	B_{min} 6.7	B_{min} 7.3	B_{min} 7.4
Void content (Marshall specimen) **% by volume**	2.5 – 3.0	2.5 – 3.0	2.0 – 3.0

*S = High traffic volume
* Factor α considers the density of the aggregate mixture

Table C 4.2. Requirements

C 4.3. SPECIFIC MATERIAL REQUIREMENTS

High quality aggregate only, Los Angeles (LA) category 20, resistance to polishing (PSV) of 51/48
Flakiness Index (FI): 20
Requirements for drainage inhibitors; drainage test for mixture (Schellenberg Test EN 12697-18)
Use of drainage inhibitor 0.3 - 1.5 % by weight, cellulose fibers generally 0.3% by weight

C 4.4. TYPE TESTING PROCEDURE

Marshall (specimen)

C 4.5. SPECIFIC PRODUCTION & APPLICATION REQUIREMENTS:

Pneumatic tyre rollers are not permitted; compaction without vibration is recommended.
Surface treatment (gritting) for enhanced initial skid resistance.

SMA	SMA 11 S	SMA 8 S	SMA 5 S
Layer thickness (cm):	3.5 – 4.0	3.5 – 4.0	1.5 – 2.0
Degree of compaction (%):	≥ 98.0	≥ 98.0	≥ 96.0
Void content (Vol.-%):	≤ 5.0	≤ 5.0	≤ 6.0

C 4.6. PERFORMANCE IN PRACTICE

Since decades SMAs show a long service-life in heavy trafficked areas like Autobahns, national roads, city roads and special applications like container terminals and runways on airports. SMA fulfils all required safety aspects and is known as one of the most economical respectively sustainable asphalt pavements.

In Germany highly stable asphalt binder courses based on the SMA concept and noise reducing SMA surface courses are showing promising results in the field.

5. HUNGARY

C 5.1 APPLICATION

SMA is used since 25 years in practice for highways, expressways, national roads, bridges and race tracks.

C 5.2 REQUIREMENTS

MSZ EN 13108-5:2016

Passing sieve in % by weight at	SMA 11	SMA 8
16.0 mm	100	-
11.2 mm	90 - 100	100
8.0 mm	-	90 - 100
5.6 mm	35 - 50	-
4.0 mm	-	28 - 48
2.0 mm	20 - 30	20 - 30
1.0 mm	10 - 21	10 - 21
0.063 mm	5 - 12	5 - 13
Binder type	45/80-65 25/55-65	45/80-65 25/55-65
Minimum binder content % by weight	B_{min} 6.2	B_{min} 6.4
Void content % by volume (Marshall specimen, 2 x 50 blows)	2.5 - 4.0	2.5 – 4.0

C 5.3 SPECIFIC MATERIAL REQUIREMENTS

Only polymer modified bitumen (pmB) is used
Requirements for filler: Minimum 7% by weight limestone filler in SMA 8 and 6% by weight in SMA 11
Water sensitivity (ITSR, %): 90 - EN 12 697-12 (15°C)
Requirements for drainage inhibitors; drain down of max. 0.3, according to Schellenberg Test (EN 12697-18)

C 5.4 TYPE TESTING PROCEDURE

Following parameters are monitored: gradation, binder content, void content (Marshall), water sensitivity, Wheel Tracking Test and binder drainage.

C 5.5 SPECIFIC PRODUCTION & APPLICATION REQUIREMENTS

Layer thickness:

SMA8 (mF):25-40(45) mm
SMA11 (mF): 35-50 (60) mm
Required degree of compaction: 97-97.5%

C 5.6 PERFORMANCE IN PRACTICE

The reputation of SMA is high in Hungary. The wearing course of high traffic roads (for example motorways) is the only/lonely solution SMA.

The reasons for use of SMA: Long lifetime, expected 10-12 years, safety aspects and environmental protection.

6. NORWAY

C 6.1. APPLICATION

Since 1985 SMA is used for highways, expressways, national roads, municipality roads, airports/runways, bridges and race tracks. Norway has three types of SMAs: SKA 8, SKA 11 and SKA 16.

C 6.2. REQUIREMENTS

NS-EN 13108-5, Vegbygging, Normaler, Handbok N200, SKA (= SMA)

SMA shall be within the requirements of NS-EN 13108-5 "Bituminous Mixtures – Material Specifications". The grading of the aggregate shall be within the limits given in table C 6.2. The binder content shall be as high as mentioned.

Passing sieve	SMA 16	SMA 11	SMA 8
22.4 mm	100		
16 mm	90 - 100	100	
11.2 mm	46 - 66	90 - 100	100
8 mm	30 - 44	47 - 64	90 - 100
4 mm		30 - 45	38 - 53
2 mm	15 - 30	20 - 32	24 - 36
0.25 mm	10 - 17	12 - 20	14 - 22
0.063 mm	8 - 12	9 - 13	10 - 14
Binder type	35/50 – 70/100 PmB	50/70 – 70/100 PmB	70/100 – 160/220
Minimum binder content % by weight	B_{min} 6.0	B_{min} 6.2	B_{min} 6.6
Fiber[1] % by weight of binder	4 - 6		

[1] Fiber amounts is based on cellulose fibers, different types of fibers my need other quantities of addition.

Table C 6.2. Grading requirements

C 6.3. SPECIFIC MATERIALS REQUIREMENTS

The properties of the materials used in Stone Mastic Asphalt (SKA) shall comply with the requirements given in Table C 7.3.

	Annual Daily Traffic (ADT)		
	ADT ≤ 5.000	ADT 5001 – 15.000	ADT > 15.000
Flakiness index	≤ 30	≤ 25	≤ 25
Los Angeles value	≤ 25	≤ 25	≤ 15
Nordic Abrasion value	≤ 10	≤ 10	≤ 7
Ratio crushed aggregate surface	$C_{50/20}$	$C_{100/0}$	$C_{100/0}$
Void content %	2.0 – 6.0	2.0 – 6.0	2.5 – 6.0
Voids filled with bitumen %	71 - 89	71 - 89	71 - 86

Table C 6.3. Requirements for materials used in` Stone Mastic Asphalt

C 6.4. SPECIFIC PRODUCTION & APPLICATION REQUIREMENTS

After paving and compaction the binder content and the aggregate grading of the SMA mixture shall be in compliance with the job mixture formula and within the tolerances.

C 6.5. PERFORMANCE

Experiences with Stone Mastic Asphalt are really good. SMA has a very good resistance to wear by studded tyres and has no problems.

7. POLAND

C 7.1 APPLICATION

SMA was laid officially for the first time in 1991. But much earlier, the first SMA-type asphalt mixture was laid in 1969 according to data from Gerhard Zichner´s publications in Bitumen magazine (in Germany). On the basis of this first applications Polish Central Administration of Public Roads released in 1971 its own technical standard ZN-71 / MK-CZDP-3. In years 1990 – 2008 for designing of SMA mixtures Guidelines of Road & Bridge Research Institute were used. Then, since 2008, there are several Guidelines published by road administration in operation, generally based on EN 13108-5 standard.
Today SMA is used for highways, national roads and provincial roads. Poland specified following types of SMAs:

- for wearing courses: SMA 11 S, SMA 8 S and SMA 5 S
- for binder courses: SMA 16 W

Designations for asphalt mixtures in Poland are generally in agreement to EN 13108, with an additional letter which means: S – wearing course, W – binder course

C 7.2 REQUIREMENTS

On national roads network the specifications for SMA asphalt mixture from Technical Guidelines "WT-2 2014 Część I, Mieszanki Mineralno-Asfaltowe, Wymagania, Chapter 8.2.5. Mieszanka SMA" are used.

SMA	SMA 11 S Traffic KR 5-7	SMA 11 S Traffic KR 3-4	SMA 8 S Traffic KR 5-7	SMA 8 S Traffic KR 1-4	SMA 5 S Traffic KR 1-4
Passing sieve in % by weight at **16 mm** **11.2 mm** **8 mm** **5.6 mm** **2 mm** **0.125 mm** **0.063 mm**	100 90 - 100 50 - 65 35 - 45 20 - 30 8 - 12	100 90 - 100 50 - 65 35 - 45 20 - 30 8 - 12	100 35 - 65 20 - 30 9 - 17 7 - 12	100 35 - 65 20 - 30 9 - 17 7 - 12	100 90 - 100 30 - 40 7 - 12
Bitumen type	PMB 45/80-55 PMB 45/80-65 PMB 45/80-80 PMB 65/105-60* PMB 65/105-80	50/70 PMB 45/80-55 PMB 45/80-65 PMB 65/105-60* MG 50/70-54-64	PMB 45/80-55 PMB 45/80-65 PMB 45/80-80 PMB 65/105-60* PMB 65/105-80	50/70 PMB 45/80-55 PMB 45/80-65 PMB 65/105-60* MG 50/70-54-60	50/70 PMB 45/80-55 PMB 45/80-65 PMB 65/105-60* MG 50/70-54-64
Minimum binder content % by weight	B_{min} 6.6	B_{min} 6.6	B_{min} 7.2	B_{min} 7.2	B_{min} 7.4
Void content % by volume (Marshall specimen, 2 x 50)	2.0 – 3.5	2.0 – 3.5	2.0 – 3.5	1.5 – 3.0	1.5 – 3.0
Rutting resistance, WTSair (60°C, 10000 cycles, in air, slab 40 mm)	0.15 or 0.10 (KR7)	0.15	0.15 or 0.10 (KR7)	0.15	0.15
Rutting resistance, PRDair (60°C, 10000 cycles, in air, slab 40 mm)	7.0	9.0	7.0	9.0	9.0

* for thin layers below 3.5 cm

Table C 7.2. Requirements for SMA in wearing courses in "WT-2 2014 Część I"

Additional remarks:

- ITSR minimum value is 90% for all types of SMA in table C8.2. (one freeze-thaw cycle test)
- Draindown value is BDmax0.3 for all SMAs
- Asphalt mixture for rutting test should be conditioned (as for AASHTO R30)
- In Silesian Province there is an additional requirement for void content after compaction 2x100 blows, minimum 2.0% by volume)
- Traffic categories are based on 100 kN axle load, in millions of passed axles in life span:
  - KR1 0,03 < N100 ≤ 0,09
  - KR2 0,09 < N100 ≤ 0,50
  - KR3 0,50 < N100 ≤ 2,50
  - KR4 2,50 < N100 ≤ 7,30
  - KR5 7,30 < N100 ≤ 22,00
  - KR6 22,00 < N100 ≤ 52,00
  - KR7 N100 > 52,00
- Design life span for asphalt (flexible) pavements is:
  - minimum 30 years for highways,
  - minimum 20 years for other public roads.

As it was mentioned before, apart from specification for National roads (WT-2) a few road administrators of province level have created their own specifications. Table C 7.3. shows requirements for SMA 16 W used for binder courses in Silesian Province managed by Zarząd Dróg Wojewódzkich w Katowicach.

SMA	**SMA 16 W KR 5-7 standard traffic**	**SMA 16 W KR 5-7 extreme traffic***
Passing sieve in % by weight at 22.4 mm 16 mm 11.2 mm 8 mm 5.6 mm 4.0 mm 2 mm 0.125 mm 0.063 mm	 100 90 - 100 63 - 73 46 - 56 36 - 45 30 - 37 25 - 30 6 - 13 6.0 - 10.0	 100 95 - 100 66 - 79 49 - 53 39 - 43 32 - 37 27 - 30 6 - 13 6.0 - 10.0
Bitumen type	PMB 45/80-80 HiMA PMB 25/55-60	PMB 45/80-80 HiMA
Minimum binder content % by weight	B_{min} 5.2 5.4 (in case of highly modified binder HiMA)	B_{min} 5.4
Void content % by volume (Marshall specimen, 2 x 50)	2.5 – 4.0	3.5 – 5.0
Void content % by volume (Marshall specimen, 2 x 100)	min 2.0	min 2.5
Rutting resistance, WTSair (60°C, 10000 cycles, in air, slab 60 mm)	0.15	–
Rutting resistance, PRDair (60°C, 10000 cycles, in air, slab 60 mm)	PRDair 7.0	–
Rutting resistance, P, (60°C, 30000 cycles, in air, slab 100 mm) – large apparatus	–	max 7.5

* extreme traffic – heavy traffic of trucks with 130 kN/axle loads or 115 kN/axle with low speed below 40 km/h

Table C 7.3. Requirements for SMA in binder courses in "WTW SMA 16 W, ZDW Katowice 2017"

For SMA mixtures, there are specified some requirements for aggregates:

- crushed stones: $C_{95/1}$ or $C_{100/0}$
- fines content: f 2
- resistance for fragmentation: LA max 25
- resistance for polishing: PSV min 50
- shape/flakiness: FI20/SI20
- angularity: Ecs30
- stiffening properties of filler: ΔR&B 8/25
- calcium carbonate content in filler: CC 70

C 7.4 TYPE TESTING PROCEDURE

Generally the Marshall compactor (2x50 blows) is used for designing the composition of SMA mixtures. Volumetric parameters as: Void content in compacted specimens, VMA, VFB are used for evaluation of the mixture. Then mixture is checked in rutting resistance, ITSR and draindown tests. No special method for designing the skeleton of SMA is applied.

C 7.5 SPECIFIC PRODUCTION & APPLICATION REQUIREMENTS

Long term observations:

- designing of SMA with 2x75 blows created too dry mixtures (used between 1990-2008) with poor durability and too high permeability,
- production of the mix without fibers or with poor quality stabilizers/fibers creates many problems with homogeneity of surface,
- there were several problems with mixing sequence in asphalt plant, depending on type of stabiliser (loose/granulated and with/without bitumen), similar problem is with stabiliser mixing time – too long destroyed loose fibers, too short cannot release fibers of granulates,
- using Material Transfer Vehicle is highly recommended to get high quality SMA layer.

C 7.6 PERFORMANCE IN PRACTICE

In 1999 the first SMA section was laid at the highway A4 in Poland. The pavement shows no failures so far and offers long lasting surface properties.

SMA became the leading flexible pavement design on Polish highways. It is proven and commonly used in surface courses. The main reasons for using SMAs are: High resistance to deformation, durability, low life-cycle costs and a good resistance to frost and water.

SMA 16 W mixtures are being used for binder course, which are used in pavements with expected extra longevity. The same mixture is also tried in the asphalt base course, as part of the Perpetual Pavements concept.

A number of noise reducing SMA 8 S applications has also been made, in the western part of Poland, where no severe winter is observed. So far, those type of mixtures, perform well.

8. RUSSIA

C 8.1 APPLICATION

SMA is used since 2000 for highways, national roads, municipality roads and bridges.
Two SMA specifications are in place in Russia at present:
GOST 31015-2002 (active till 2019) and preliminary state standard PNST 183-2016 (final revision). In 2019 the GOST 3106-2002 will be replaced by PNST 183-2016.

The aggregates size distribution composition of the mixtures (PNST 183-2016)

Sieve size, mm	Pass through a sieve, % weight			
	SMA 22	SMA 16	SMA 11	SMA 8
31,5	100	–	–	–
22,4	90 - 100	100	–	–
16,0	50 - 65	90 - 100	100	–
11,2	30 - 50	50 - 65	90 - 100	100
8,0	24 - 40	40 - 55	50 - 65	90 - 100
5,6	–	–	35 - 45	35 - 55
4,0	20 - 35	23 - 38	25 - 40	25 - 45
2,0	16 - 26	18 - 28	20 - 30	20 - 30
0,063	8 - 12	8 - 12	8 - 12	8 - 12

C 8.2 REQUIREMENTS (PNST 183-2016)

Specification	SMA 22	SMA 16	SMA 11	SMA 8
	Main parameters			
Voids in laboratory (by Marshall-Specimen or Gyrator-Specimen) in %	2.5 to 5.0	2.0 to 4.0	2.0 to 4.0	1.5 to 3.5
Voids in mineral aggregate (VMA) in %	15	16	16	16
Water adsorption in % - Lab samples - Core samples	1.5-4.5 5.0	1.0-3.5 4.0	1.0-3.5 4.0	0.5-3.0 3.5
Maximum depth of rutting, in mm	3.5	3.5	3.5	3.5
Water resistance	0.85			
	Additional parameters			
Minimum tensile strength in MPa	7.5			
Relative strength in tension	0.005			
Gradient curve of rutting 1.000 circles	0.15			

Table C 8.2 Requirements

C 8.3. SPECIFIC MATERIALS REQUIREMENTS

The crushed stone from igneous and metamorphic rocks or sedimentary rocks. The sand of eliminations of crushing. The mineral powder from carbonate rocks. Bitumen 35/50, 50/70, 70/100, 100/130, 130/200; PmB 40, 60, 90 (according to the climate zone).

C 8.4 TYPE TESTING PROCEDURE

Water adsorption, Schellenberg test, wheel-tracking test.

C 8.5 SPECIFIC PRODUCTION & APPLICATION REQUIREMENTS

SMA is used for Surface layer. Regular thickness from 2,5 to 6,0 cm.
Temperature limits for mixing is 155-165°C, for paving is 120°C.

C 8.6 PERFORMANCE IN PRACTICE

SMA is reliable and has got a long life behaviour. It is the best solution for high traffic roads with the best resistance to abrasion from studded winter tyres.
The demand of SMA is growing annually. It is used as the main type for Highways and Federal Roads.

9. SPAIN

C 9. 1 APPLICATION

SMA mixtures have been used in Spain for 25 years, although they have been scarcely applied and limited to specific projects where top performance was required.
Airports, Formula 1 racing tracks, motorways and urban roads have been the main uses in Spain. The first experiences dated are on the AP-7 toll highway and at various airports.
Spain does not have official specifications on SMA mixtures, beyond those indicated in standard EN 13108-5, which has limited its use. All the aforementioned experiences have been carried out under the protection of road administrations that have their own authority to specify products.
The oldest experiences have been confined to formulations from central Europe, but the most modern experiences are immersed in the search for more specific features such as noise reduction for which the typical void content in SMA mixtures have been slightly increased. Also the use of PMB binders or crumb rubber have been topics dealt in these new development. Besides, some projects are also being carried out with small sized aggregate mixtures (5-6 mm).
As already mentioned above, the first relevant experiences took place on the AP-7 toll motorway (T00 traffic) in the 90's. Starting from conventional gradings for SMA, various combinations of binders and fibers were tested. Finally, polymer modified bitumens of high elastic capacity were used. The goal was having high quality and resistant surface layers, replacing the use of porous mixtures.

C 9.2 REQUIREMENTS

Nowadays, in Spain there are no technical specifications for SMA mixtures, so the various experiences have developed product features optimised for each project. Some of the most used references are those of the R & D project "ProyectoSMA" http://www.proyectosma.eu/ in which a draft of specification is launched, whose main characteristics are:

Grading:

Mix	Sieves (% pass)							
	22	16	11,2	8	4	2	0,5	0,063
SMA8			100	90-100	30-45	25-35	12-22	7-10
SMA11		100	90-100	55-80	22-33	20-30	12-20	6-10
SMA16	100	90-100	55-80	35-55	17-35	15-25	10-28	6-10

Binder:

	TRAFFIC CATEGORY				
	T00 AND T0	**T1**	**T2 AND T31**	**T32 AND HARD SHOUL-DERS**	**T4**
SURFACE COURSE	PMB 45/80-75 PMB 45/80-65	PMB 45/80-65 PMB 45/80-60 BMAVC-1 BMAVC-2 BMAVC-3	PMB 45/80-60 BC 50/70 B 50/70	BC 50/70 B 50/70 B 70/100	
BINDER COURSE	PMB 45/80-75 PMB 45/80-65 BC 35/50 BC 50/70 B 35/50 B 50/70	PMB 45/80-60 BC 35/50 BC 50/70 B 35/50 B 50/70	BC 50/70 B 35/50 B 50/70	BC 50/70 B 50/70	

Binder content and layer thickness:

LAYER	MIX	THICKNESS (cm)	MINIMUM BINDER CONTENT (% by weight)
SURFACE COURSE	SMA8	2-4	6,0
	SMA11	3-5	5,8
	SMA 16	4-8	5,8
BINDER COURSE	SMA16	5-9	5,6

Binder drainage inhibitors:
Typical dosing of those additives is 0,3-1,0 % (by weight).

10. SWEDEN

Sweden uses four types of SMA: SMA 4, SMA 8, SMA 11 and SMA 16. SMA 11 and SMA 16 are most common and used extensively on the arterial road network. Main drivers for the use are for SMA 16 mm, the durability and wear resistance from studded tyres. SMA 11 and SMA 8 reduce noise levels and have a good resistance to shear forces in roundabouts.

C 10.1. APPLICATION

First trials since 1974, standard on motorways and main roads since 1988. Application areas of SMA are highways, expressways, national roads, municipality roads, bridges and airfields.

C 10.2. REQUIREMENTS

Specification "Trafikverket, The Swedish Transport Administration, publication 2011:266 TRVKB 10 Bitumenbundna lager". RAP allowed up to 20% in surface layers and 30% in other layers as of 2017. No RAP allowed if PMB is used.
Types and required composition: (see table below)

Passing sieve	SMA 16	SMA 11	SMA 8	SMA 4
22.4 mm	100			
16 mm	90 - 100	100		
11.2 mm	-	90 - 100	100	
8 mm	27 - 50	35 - 60	90 - 100	
5.6 mm	-	-	-	100
4 mm	20 - 32	24 - 35	28 - 49	90 - 100
2 mm	16 - 29	19 - 30	20 - 30	25 - 40
0.5 mm	12 - 24	12 - 24	12 - 22	15 - 25
0.063 mm	9 - 12	9 - 13	9 - 13	9 - 13
Stabilizing additive in % by weight	0.3 – 1.5			

Table C 10.2.1: Requirements

Quality requirements	Annual Daily Traffic, per lane (AADT)			
	500 – 1500	1500 – 3500	3500 -7000	> 7000
Flakiness index FI	≤ 20	≤ 20	≤ 15	≤ 15
Los Angeles value	≤ 25	≤ 25	≤ 25	≤ 20
NBR, Nordic abrasion test	≤ 14	≤ 10	≤ 7	≤ 7

Table C 10.2.2: Requirements aggregates

Binder type	Minimum binder content in % by weight			
	SMA 16	SMA 11	SMA 8	SMA 4
50/70	6.0	6.2	6.4	-
70/100	6.0	6.2	6.4	6.6
100/150	5.8	6.0	6.2	6.6
160/220	5.8	6.0	6.2	6.4

Table C 10.2.3: Binder type and contents

Binder type	Value for void content Marshall specimen, % by volume			
	SMA 16	SMA 11	SMA 8	SMA 4
50/70	2.0 – 3.5		2.0 – 4.0	
70/100				
100/150				
160/220				

Table C 10.2.4: Air void content Marshall specimen

C 10.3. SPECIFIC MATERIAL REQUIREMENTS

Aggregate: >90% crushed, anti-stripping agents required in all mixes (amines, cement or lime) and fibers.

C 10.4. TYPE TESTING PROCEDURE

Marshall specimen testing at several binder contents, valid ITSR test.

C 10.5. SPECIFIC PRODUCTION & APPLICATION REQUIREMENTS

Even if it is not a requirement for SMA, the use of material transfer devices (i.e. shuttle buggy or similar) have increased and due to other contract requirements for segregation. Commonly used on high volume roads, but rarely in cities.

C 10.6. PERFORMANCE IN PRACTICE

SMA provides good skid resistance, wear resistance, deformation resistance, ageing properties, fatigue properties and some noise reduction.

11. SLOVENIA

Three types are used: SMA 11, SMA 8 and SMA 4

C 11.1 APPLICATION

SMA is used since 1996 on highways and fast roads (Highways, Expressways), National Roads, Municipality Roads, Bridges and other asphalt surfaces with heavy traffic load. The main reasons are:

Resistance to deformation
Durability
Less noise
More comfortable driving in the rain
Safety aspects.

C 11.2 REQUIREMENTS

In Slovenia SMA is produced in accordance with the standard SIST EN 13108-5 and the national appendix SIST 1038-5.

C 11.3 SPECIFIC MATERIAL REQUIREMENTS

Mixture:
Void content 2-4.5 %
Filling voids with bitumen 74-89%
LA: 20 - 25
PSV > 50 or PSV > 30 for protecting layer on bridges
Bitumen:
The most used type of bitumen for SMA is PmB 45/80-65
Rarely also standard bitumen e.g. B 50/70.

C 11.4 TYPE TESTING PROCEDURE

Resistance to low temperatures (TRST and UTST)
Resistance to fatigue
Stiffness
Resistance to lasting transformation

C 11.5 SPECIFIC PRODUCTION & APPLICATION REQUIREMENTS

Thickness from 2 to 5 cm (depending on aggregate size), standard thickness: 4 cm
Required degree of compaction: minimum 97.0%
Voids in layer: 1.0 - 7.5%
Resistance to permanent deformation - Wheel Tracking Test - PRDair 5%

C 11.6 PERFORMANCE IN PRACTICE

Life expectancy of SMA on highways is from 15 to 20 years in Slovenia, problems with rutting are gone. Other characteristics have been also improved like durability, less noise and water separation.

At the beginning problems like cracks encountered in some individual sections and contractors faced some practical challenges. Cracks in the SMA surface were eliminated by a systematic approach and the introduction of additional laboratory tests for cold temperature behaviour.

12. UNITED KINGDOM / SCOTLAND

SMA 20, SMA 14, SMA 10 or SMA 6 are generally used.

C 12.1. APPLICATION

SMA and variants have been used for all categories of paved areas including highways, from the national high speed to local networks; on airports/runways, bridges, race tracks and parking areas. SMAs have been developed since they were first researched in the early 1990´s.

C 12.2. REQUIREMENTS

SMA is specified in different ways according to the needs of the client. Generally, this is in compliance with European specification EN 13108-5 and the National Application Document, PD6691, in relation to target grading, binder content, voids content and other mechanical properties e.g. stiffness and resistance to deformation. Table C 12.2 of PD6691 outlines the limits of target composition for surface, binder and regulating course mixtures.

Extract from PD6691: 2015 + A1: 2016

Table C 12.2: Requirements > limits for target composition for SMA mixtures

D mm	6	10	14	20
Sieve	**Passing sieve % by mass**			
31.5				100
20			100	94 - 100
14		100	93 - 100	=
10	100	93 - 100	35 - 60	25 - 39
6.3	93 - 100	28 - 52	22 - 36	22 - 32
4	26 - 51	=	=	=
2	24 - 39	20 - 32	16 - 30	15 - 26
0.5[A]	-	-	-	-
0.25[A]	-	-	-	-
0.063	8.0 - 14	8.0 - 13	6.0 - 11	8.0 - 11
Binder content Percentage (m/m) of Total mixture B_{act} [B)]	6.6	6.2	5.8	5.4

EAPA

A) The 0.25 mm and 0.5 mm sieves are not included in BS EN 13108-5 but have traditionally been used in the UK for control of these mixtures, and it is advised that values are recorded.
B) Mixtures designed with polymer modified bitumens conforming to BS EN 14023 may result in a reduced actual target binder content to those shown in Table C 12.2.

NOTE: The binder content B_{act} relates to added binder content, before correcting for aggregate / mixture density to determine minimum binder content B_{min}, as required in the BS EN 13108 series.

Some clients may also specify installed property requirements. This is particularly the case for the high-speed network managed by Highways England and other devolved Government bodies and Local Authorities, and include: installed and retained macrotexture, noise characteristics etc. Some properties are evaluated prior to production only and are not used for compliance, but as a guide for procurement. Such properties are outlined in product certificates, such as the HAPAS scheme for product approval of Thin Surface Course Systems (TSCS), when they are not covered by CE Marking of the product to EN 13108-5. Materials which comply with other parts of EN13108 series (and other product standards) are also permitted for approval as TSCS, provided they also meet the performance requirements.

C 12.3. SPECIFIC MATERIAL REQUIREMENTS

Some properties are indicated below, but not all, as these are called up from other Standards and National Guidance Documents and Specifications and/or in relation to site classifications and categories as defined by contract designer/specifier.

Property	**Requirement**	**'Generic' SMA (binder, regulating or surface courses)**	**SHW Cl942 – SMA as TSCS**
Aggregates to EN 13043			
Coarse Aggregate - Type	Crushed rock or gravel	NOT Limestone for surface course on roads	NOT Limestone
	Steel slags of specified density	✓	✓
Particle Shape	Flakiness Index	FI_{20}	
Fines in coarse aggregate	Fines Content	f_4	
Microtexture	Polished Stone Value	As required for site category / classification	
Other properties	As required for site category / classification	✓	Aggregate Abrasion Value; Los Angeles Coefficient (LA) - not greater than LA_{30}
Fine Aggregate - Type	Crushed coarse aggregate or flint gravel	NOT Limestone for surface course on roads	NOT Limestone
Fines in fine aggregate	Fines content	f_{22}	
(Added) Filler Aggregate - Type	Crushed rock, crushed slag, hydrated lime, cement or other material approved	✓	✓
Filler - properties	Grading and density		✓

Binder – may be blended with natural asphalt in accordance with BS EN 13108-4			
EN 12591 – paving grade bitumen	Preferred grade 40/60, blending permitted	✓	✓
EN 14023 – polymer modified bitumen	No preferred grade	✓	✓

Additives
Permitted subject to client approval - includes pigments, fibers and other mixture modifiers.

Reclaimed asphalt			
Classified to EN 13108 - 8		"All-in" reclaimed asphalt not permitted	
	Foreign Matter	Surface course F_1; binder course F_5	
	Maximum Content	<10% - Surface Course <50% - Binder course	✓
Binder properties	Penetration	If greater than 20% of mixture – P_{15}.	

Mixture Properties			
Design Void content	Lab design / trial strip	Surface course – $V_{min1,5}$; V_{max5}. Binder course - core pairs, $V_{max6,0}$; sets of six cores, $V_{max4,0}$.	As specified, currently under review
Resistance to permanent deformation	Lab design (small device) – test temperature depends on site category	Surface & Binder course – NR or WTS_{AIR1}	WTS_{AIR1}
Binder drainage		$D_{0,3}$	
Water sensitivity		$ITSR_{NR}$	As specified, $ITSR_{70}$ currently under review
Temperature		Production max, no min	

In-situ properties			
Layer thickness		Target thickness ± installation tolerances	
Torque Bond	As part of approval process	×	≥400 KPa
Surface macrotexture	As installed	As required for site category / classification	As required for site category / classification – under review
	After 2 years	×	>1,0mm – under review
Noise		×	As required for site category / classification
Surface integrity	Excludes external sources of damage	×	5 years – under review
Surface Condition	By visual inspection and ranking		As part of approval process
Contractor installation requirements	Line, level etc. tolerances	National Standard for laying	Installation quality plan and quality assurance scheme
	Temperature	Installation min recommended (except for "Warm Mix Asphalts") to National Standard	
Some in-situ properties of surface courses, such as skid resistance, are generally not required to be declared, but will often be assessed as part of contract compliance in relation to the site requirements, and used in asset management procedures to determine maintenance needs.			

C 12.4. TYPE TESTING PROCEDURE

In compliance with EN 13108 Part 20 for CE marked products – it is unlikely that non-CE marked products will be permitted for the majority of applications, but some private (non-Governmental) developments may not require this and proprietary SMA-type products have been used.

C 12.5. SPECIFIC PRODUCTION & APPLICATION REQUIREMENTS

In compliance with EN 13108 Part 21 for production of CE Marked Products and National Standard for laying / application – BS 594987 (this standard also includes a number of recommended protocols for Type Testing when validated by site-scale trials). Producers may choose to carry out testing for FPC more frequently than the minimum frequencies required in Part 21. A National Quality Assurance Scheme for asphalt laying (NHSS16) is generally required for public sector clients, which includes requirements for a quality plan and control procedures, as well as competency requirements of contractors' staff. Producers may limit approval to supply their HAPAS products to other contractors, subject to their own assessment of complying with the specific quality plan for installation of the product.

C 12.6. PERFORMANCE

The general characteristics of SMA in the UK are that it is a safe, smooth, quiet running surface, which is durable. The typical expected service life of SMA in the UK is often cited as being between 12 and 15 years. Research on durability has often encompassed all types of Thin Surface Course Systems and homogenised data may not separate SMA from other variants. Given this, research continues to develop systems that are even more durable, given projected traffic volume increases, so that maintenance interventions are less frequent and hence disruption to road users is minimised and whole life cost is optimised.

Industry and client organisations such as Highways England and Transport Scotland continue to carry out research on past performance and enhancements to TSCS. For example, Transport Scotland published its TS2010 specification (in 2010) with more rigid compositional requirements and fewer degrees of freedom in design for producers, but without some in-situ properties e.g. macrotexture. Ongoing monitoring currently predicts service lives in excess of 15 years.

Highways England is also carrying out its own research on “next generation” TSCS focusing on enhanced durability, but is not yet relaxing any in-situ requirements such as macrotexture or noise.

Much experience has also been gathered in relation to site characteristics in relation to durability e.g. weak substrata and/or those encountered on evolved local roads are not always suitable for application of TSCS and may result in relatively early failure. Financial constraints may also have sought for TSCS to provide surface solutions to what are essentially underlying structural issues, with very limited success.

13. CHINA

Generally SMA 13 is used.

C 13.1 APPLICATION

Since 1994 four types of SMA were developed: SMA 20, SMA 16, SMA 13 and SMA 10. SMA is mainly used as surface courses for heavy duty pavements.

C 13.2 REQUIREMENTS

"Technical Specification for Construction of Highway Asphalt Pavements", JTG F40 – 2004.
Types and required compositions:

Type	SMA 20	SMA 16	SMA 13	SMA 10
Mineral aggregate (%)	Crushed aggregate, crushed sand recommended, Manufactured filler			
26.5 mm	100			
19 mm	90 - 100	100		
16 mm	72 - 92	90 - 100	100	
13.2 mm	62 - 82	65 - 85	90 - 100	100
9.5 mm	40 - 55	45 - 65	50 - 75	90 - 100
4.75 mm	18 - 30	20 - 32	20 - 34	28 - 60
2.36 mm	13 - 22	15 - 24	15 - 26	20 - 32
1.18 mm	12 - 20	14 - 22	14 - 24	14 - 26
0.6 mm	10 - 16	12 - 18	12 - 20	12 - 22
0.3 mm	9 - 14	10 - 15	10 - 16	10 - 18
0.15 mm	8 - 13	9 - 14	9 - 15	9 - 16
0.075 mm	8 - 12	8 - 12	8 - 12	8 - 13
Binder type	Polymer modified and standard bitumen			
Type testing requirement (Marshall specimen):				
Void content (%)	3-4			
VMA (%)	≥17			
VFA (%)	75-85			
Layer thickness	More than 2-2.5 times of the nominal maximum aggregate size			

Table C 13.2: Requirements

C 13.3 SPECIFIC MATERIAL REQUIREMENTS

Dosage of cellulose fibers: ≥ 0.3 %
Drainage test for mixture: ≤ 0.1 % (tested with modified binder); ≤ 0.2 % (tested with unmodified binder).

C 13.4 TYPE TESTING PROCEDURE

Marshall specimen

C 13.5 SPECIFIC PRODUCTION & APPLICATION REQUIREMENTS

Maximum temperature at production is 195°C with a minimum laying temperature of 160°C.
Pneumatic tyre rollers not permitted

C 13.6 PERFORMANCE IN PRACTICE

SMA provides a rut resistant and very durable surface course.

14. TURKEY

C 14.1. APPLICATION

First applications of SMA have been started in 2000. Since 2005 SMA has been widely used for all categories of paved areas especially on highways and motorways, rarely on urban roads, airports/runways.

C 14.2. REQUIREMENTS

SMA is specified in Highways specification (Karayolu Teknik artnamesi- Kısım 408-Ta Mastik Asfalt) for surface and binder courses. Highways specification is partly in compliance with European standard EN 13108-5. Asphalt producers are obliged to comply with European standards besides highways specification to put their products on the market. Table 1 shows the limits of target composition for surface and binder mixtures.

Table C 14.2: Requirements for target composition for SMA mixtures

	Surface course		**Binder course**
Sieve [mm]	**Type-1 Passing %**	**Type-2 Passing %**	**Passing %**
25			100
19.0	100		92-100
12.5	90-100	100	73-83
9.5	50-75	90-100	56-66
4.75	25-40	25-45	32-42
2.00	20-30	20-30	25-30
0.425	12-22	12-22	14-20
0.180	9-17	9-17	9-15
0.075	8-12	8-12	7-11
Aggregate requirements	$LA_{25}/MD_{20}/MS_{14}/PSV_{50}$(surf)$PSV_{40}$ (binder layer)/$C_{100/0}$ / FI_{20}		
Binder content (B50/70, PMB) % (m/m) Min[1)].	5.8	6.5	5.2
Fiber % by weight of asphalt mix	0.3-1.0		0.2-0.8

SMA Mixture Properties	
Volumetric properties: - Void content % by volume (Marshall specimen, 2 x 50) - VMA	Lab design
Resistance against permanent deformation (Wheel Tracking Test) – EN 12697-22;	Lab design (30.000cycles at 60 C)
Binder drainage EN 12697-18	Lab design
Water sensitivity – AASHTO T 283 ITSR	Lab design

SMA paving requirement	Surface Type-1	Surface Type-2	Binder
Layer thickness (mm):	35-50	25-40	60-100
Degree of compaction (%):	98-100	98-100	98-100
Void content (Vol.-%):	≤ 5.0	≤ 5.0	≤ 5.5
Surface texture mm, EN 13036-1	<1.0	<0.8	-

C 14.3. PERFORMANCE IN PRACTICE/ REPUTATION

Since 2005, SMAs have been widely used for surface course in motorways and the heavily trafficked state roads. Generally, SMA is produced with PMB. Good performance and long service-life are provided in heavy roads and maintenance interventions are less frequent, therefore it is known the most economical sustainable asphalt pavements.

ANNEXE D: THE EUROPEAN STANDARD FOR SMA – EN 13108-5 (EDITION 2006/AMENDMENT 2008)

In the European Standard for SMA (EN 13108 - 5) the mixture "Stone Mastic Asphalt" is defined as a "gap-graded asphalt mixture with bitumen as a binder, composed of a coarse crushed aggregate skeleton bound with a mastic mortar". It is meant for application in surface courses of roads, airfields and other paved areas for all kinds of traffic and climates.

In the EN 13108-5 the following types are distinguished: SMA D4, D5, D6, D8, D10, D11, D12, D14, D16, D20 and D22. For the constituent materials a broad description will be given of aggregates, binders, manufactured filler, additives and reclaimed asphalt.

- Mixture design (type testing): Voids content: The type testing requirement is established, for example void content of Marshall specimen has to be 1.5-8.0 % by volume.

- Permanent deformation: Requirements for Wheel Tracking Test (empirical procedure) and Triaxial Test (fundamental procedure) are determined.

SMA	**D4**	**D5**	**D6**	**D8**	**D10**	**D11**	**D12**	**D14**	**D16**	**D20**	**D22**
Passing sieve (% by weight)											
31.5 mm											100
22.4 mm										100	90 - 100
20.0 mm									100	90 - 100	
16.0 mm								100	90 - 100		
14.0 mm						100	100	90 - 100			
11.2 mm					100	90 - 100	90 - 100				
10.0 mm				100	90 - 100						
8.0 mm			100	90 - 100							
6.3 mm		100	90 - 100								
5.6 mm	100	90 - 100									
4.0 mm	90 – 100										
2.0 mm	25 – 45	20 - 40	20 - 40	20 - 40	20 - 35	20 - 35	20 - 35	15 – 30	15 – 30	15 – 30	15 – 30
0.063 mm	5 - 14	5 - 14	5 - 14	5 - 14	5 - 13	5 - 13	5 - 13	5 - 12	5 - 12	5 - 12	5 – 12
Min. binder content % by weight	B_{min} 5.0 – 7.6										
Void content Marshall % by volume	V_{max} 3.0 – 8.0 V_{min} 1.5 – 6.0										

ANNEXE E: BIBLIOGRAPHY/ABBREVIATIONS

The text in this document is based on the experiences provided by the EAPA member associations and furthermore the following literature was used:

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ABBREVIATIONS USED IN THIS DOCUMENT

AC	Asphalt Concrete
AC-TL	Thin Layer Asphalt Concrete
AC VTL	Asphalt Concrete Very Thin Layer
ADT	Annual Daily Traffic
CEN	European Committee for Standardization (French: Comitè Européen de Normalisation)
EVA	Ethyl Vinyl Acetate
HDP	Heavy Duty Pavements
HRA	Hot Rolled Asphalt
Mastic-A	Mastic Asphalt
PA	Porous Asphalt
PmB	Polymer modified Bitumen
PSV	Polished Stone Value
RA	Reclaimed Asphalt
RAP	Reclaimed Asphalt Pavement
SBS	Styrene Butadiene Styrene
SMA	Stone Mastic Asphalt
SMA B C	Stone Mastic Asphalt Binder Courses
SMA NR	Noise-Reducing Stone Mastic Asphalt
UTLAC	Ultra Thin Layer Asphalt Concrete
VCA	Voids in the Coarse Aggregate
VFB	Voids Filled with Binder
VMA	Voids in the Mineral Aggregate
2L-PA	Double Layered Porous Asphalt

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