

## Optimized road noise asphalt pavement technologies

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### ABSTRACT

From a medical point of view, noise has long been recognized as a stress factor for humans. A high level of noise makes it difficult to concentrate, creates not only stress but also health problems for the ears, and also has a damaging effect on the cardiovascular and endocrine systems - noise makes you sick! Road traffic accounts for a significant share of total noise, especially in conurbations. In order to effectively reduce noise emissions, surface courses can be installed as road surfaces that generate particularly little noise in interaction with the vehicle tyre. The road surface must therefore contribute to reducing traffic noise at the source. The entire work is divided into two parts.

### 1. Introduction

Noise is any kind of sound that can disturb, annoy or even harm people's health (Mihaylova, 2008). Passing cars, the drone of an aeroplane in the air, conversations in an open-plan office - noise is manifold and is one of the greatest health risks, especially in cities. According to a WHO study, traffic noise is the environmental problem with the second strongest impact on our health after air pollution. High noise levels make it difficult to concentrate, cause stress and health problems for the ears, and also have a harmful effect on the cardiovascular and endocrine systems. From today's perspective, about one in three young people will therefore need hearing aids by the age of 50," says Anna Streissler, education expert and head of the "Learning without Noise" project at the Umweltdachverband (Austrian environmental umbrella organization) (STANDARD, 2019). The reduction of traffic noise has gained in importance in recent years. Active noise protection in the form of walls or embankments is reaching its limits or can even only be guaranteed through the use of enclosures (Ripke, 2011).

Especially in the area of noise emission, which is dominated by the rolling noise of the tyres in the speed range of motorways and motorways, a differentiated picture emerges here with the types of surface course used. Here, depending on the traffic volume and composition, a compromise must be found between the acoustic properties and the load-bearing capacity of the

road surface. While open-pored asphalt wearing courses have very good acoustic properties, they can only be used to a limited extent on highly loaded or stressed routes due to the associated reduction in service life.

Road pavements such as asphalt concretes or washed concrete pavements have a good durability even with high proportions of heavy traffic, but this structural durability comes at the price of increased noise emissions. In order to guarantee a high quality of all parameters, noise-reducing dense or semi-dense asphalt wearing courses are of great importance. At the time of their installation, these exhibit good acoustic properties and a long service life, even on highly loaded stretches of road. However, a reduction in their noise-reducing effect is evident, which can assume an extent of 3-5 dB(A) within 5 years (BMVI, 2017).

Rolled asphalts can be further subdivided into dense and open-pore asphalt (OPA). Dense asphalt concrete (AC) and stone mastic asphalt (SMA) can be described as dense. As a special form of rolled asphalt, the asphalt wearing courses with more voids, which can be described as "semi-dense", have emerged since around 2005. These include the construction methods noise-optimized asphalt wearing course (LOA) and low-noise stone mastic asphalt (SMA LA). The dense rolled asphalts such as asphalt concrete (AC) and have a noise-optimized surface design.

## 2. Effective mechanisms of noise-reducing road surfaces

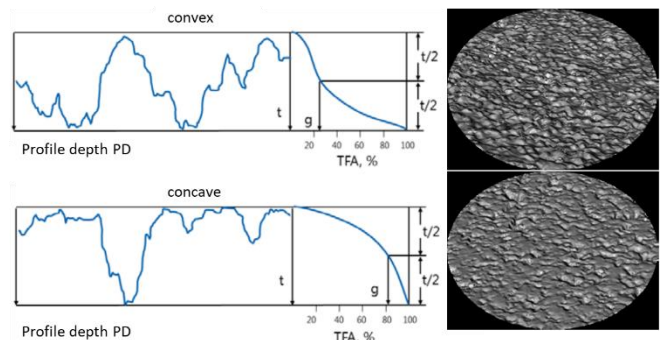
### 2.1 General

The noise generated by road traffic has two sources, on the one hand the sound caused by the rolling tyres on the road surface, and on the other hand the engine noise. Due to the overlapping of engine noise and tyre-road noise, noise-optimized asphalt wearing courses have an effect from speeds > 30 km/h. In the case of trucks, the drive noise dominates. For HGVs, the drive noise dominates up to about 70 km/h. This means that even at low speeds, noise is not a problem for the driver. Thus, even at low speeds for passenger car traffic, noise reduction is possible through a low-noise road surface. The generation mechanisms for the rolling noise can be traced back to two different physical causes (ASPHALTA, 2018):

- Mechanical excitation of the tyre by the road surface to vibrations
- Aerodynamic processes in the tyre-pavement contact area
- Favourable acoustic properties of road surfaces are based on two different mechanisms:
- Acoustically favourable roughness elements (texture) to minimize the mechanical excitations
- Cavities to absorb sound and avoid aerodynamic vibration excitation (air-pumping effect).

Noise-reducing asphalt wearing courses are, by definition, asphalt wearing courses that lead to a reduction in tyre-road noise due to their surface texture. In addition, accessible voids can lead to sound absorption. A correction value  $D_{Stro}$  was assigned to these layers (ASPHALTA, 2018).

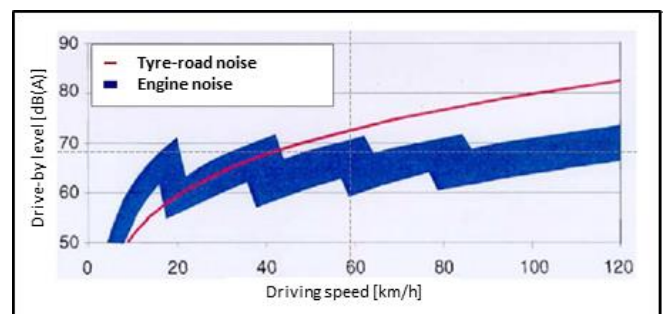
Through the targeted production of low-noise surface textures, whose geometric design does not change as much as possible over the period of use, pavements can be produced that can be expected to have a long acoustic service life with slow-moving traffic. The characteristic of the acoustically favourable surface texture is a concave shape ("plateaus with ravines"). Rock grains on the surface of the asphalt wearing course are leveled by rolling to form a flat surface, which is interrupted by depressions (Fig.1). In addition, accessible voids can lead to absorption of sound (ASPHALTA, 2018).



**Figure 1.** Representation of different texture types (edited by author)

Source: ASPHALTA Prüf- und Forschungslaboratorium GmbH, 2018

Figure 2 shows the influence of tyre-road noise and engine noise on the overall sound event during the accelerated pass-by of a passenger car (Haberl, 2011).

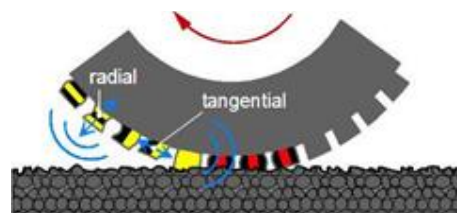


**Figure 2.** Influence of tyre-road noise and engine noise of a passenger car on the overall sound event (edited by author)

Source: J. Haberl, 2011

### 2.2 Mechanical sound excitation of the tyre

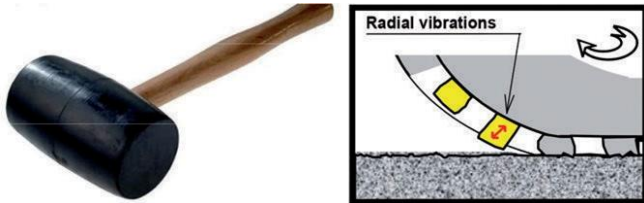
The deformation of the tyre due to the rolling process leads to a local change in the dynamic stiffness and thus to a mechanical vibration excitation of the tyre. This excitation also affects the profile blocks in the contact area. The blocks are deformed during rolling under the action of large tangential and radial dynamic forces. When the profile blocks lose contact with the road surface, they oscillate in both radial and tangential directions (Fig.3). This effect is in principle only dependent on the existing tyre profil; with a completely smooth road surface, these vibration processes would also take place (Haberl, 2011).



**Figure 3.** Mechanical vibration excitation of a tyre profilpad on a rolling tyre

Source: J. Haberl, 2011

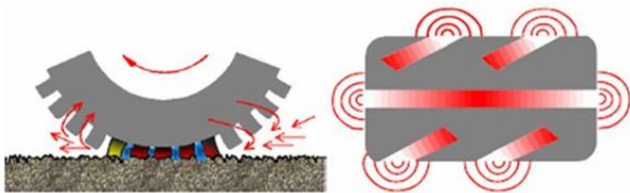
These are generated through impact between tyre tread pattern and pavement surface. There is also an influence from the deformation of the tyre around the contact area. In summary, this mechanism is strongly related to features of tyre tread patterns and pavement texture. A practical example of this mechanism could be the effect of thousands of small hammer strokes occurring every second, each generating sound. Figure 4 depicts this practical example of mechanical vibrations (PIARC, 2013).



**Figure 4.** Mechanical vibrations between tyre-pavement (Hammer Effect)  
Source: PIARC, 2013

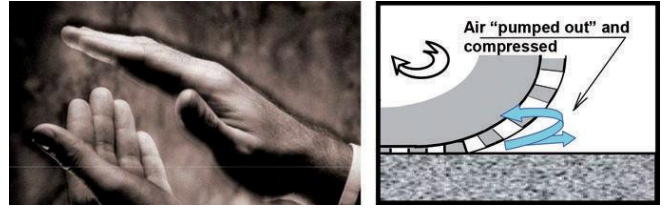
### 2.3 Aerodynamic sound excitation of the tyre

The basis for aerodynamic sound excitation of the tyre is the compressible medium air. This compressibility means that the air in the contact area between the tyre and the road is not only displaced, but also compressed in the cavities at high dynamic pressure. If the tyre continues to roll, these cavities open up again and the trapped air escapes explosively at the end of the tyre contact patch, which is known as the air-pumping effect (Fig. 5). This effect is manifested by the radiation of higher-frequency sound components with a frequency greater than 1 kHz. This sound radiation is all the greater the more closely the profile grooves are sealed off from the road surface, up to the extreme case of a smooth surface (Haberl, 2011).



**Figure 5.** Aerodynamic vibration excitation of the tyre, air-pumping effect (left) and resonance phenomena (right)  
Source: J. Haberl, 2011

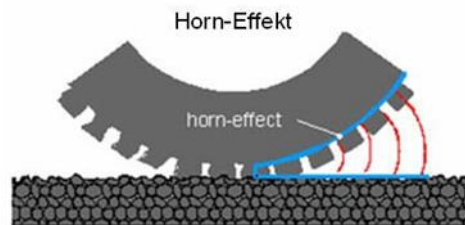
These are generated between the road surface and the tyre grooves. As the tyre rolls along the pavement, air is squeezed out, and some is trapped and compressed. Later, as the tyre loses contact with the pavement, what was trapped air is now forced out and in some cases, air is sucked back in. This happens hundreds or thousands of times per second. A practical example is clapping hands, where much of the sound that is heard is air being pushed away quickly. Another very common example of air vibration is whistling, where air is forced out of a small opening, generating sound as a result. Figure 6 displays the air vibration mechanism (PIARC, 2013).



**Figure 6.** Air vibrations between tyre-pavement (Clapping Effect)  
Source: PIARC, 2013

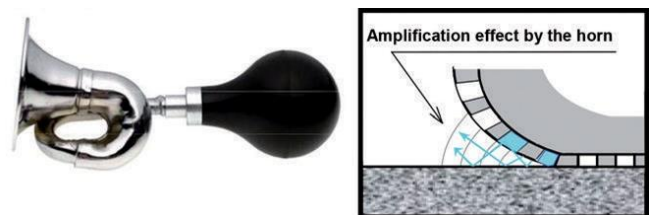
### 2.4 Sound emission and horn effect

The curved tread of the tyre and the road surface create a kind of funnel that behaves like a loudspeaker towards the existing sound components and significantly amplifies the sound radiation in the frequency range between 1 and 3 kHz. The principle of the so-called horn effect is shown schematically in Fig. 7 (Haberl, 2011).



**Figure 7.** Horn effect between tyre and road surface  
Source: J. Haberl, 2011

This effect is generated by the geometry of the tyre and the pavement, which when in contact forms a wedge-shaped segment of open air. This air creates multiple reflections of sound similar to those reflections that occur within a musical horn or megaphone. However, in the case of the tyre, the horn is poor as it is open on two sides. This results in significant amplification in the forward and aft directions and distortion of some frequencies. Figure 8 displays the acoustical horn amplification mechanism (PIARC, 2013).



**Figure 8.** Acoustical horn amplification mechanism  
Source: PIARC, 2013

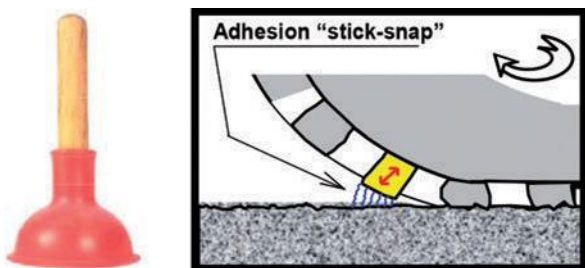
“Stick-Slip” effect is generated by the shifting adhesion (stick) and gliding (slip) of the tyre tread pattern. The tyre is subject to horizontal forces in the contact area between tyre and pavement surface which generate vibrations. As the tyre is continually deformed and distorted, it will mostly stick, but also periodically slip once a critical limit is reached.

These “corrections” under each tread block happen thousands of times a second, thus generating high frequency sound. A practical example of this effect can be observed at a basketball game, where the sound of sneakers squeaking on the court can be heard. This same type of sound is produced as a tyre rolls along the pavement. Figure 9 shows a simulation of the tangential motions observed at the tyre-pavement contact area and also shows the “sneaker effect” (PIARC, 2013).



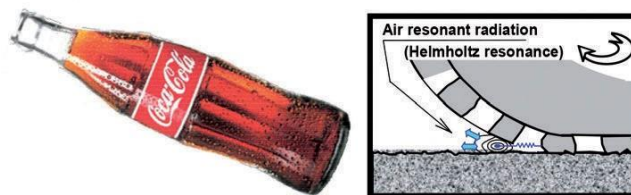
**Figure 9.** Stick-Slip mechanism between tyre-pavement (Sneaker Effect)  
Source: PIARC, 2013

“Stick-Snap” effect is also known as suction pad effect, and is generated when the tread pattern abruptly leaves the pavement surface at the rear of the tyre-pavement contact area, which leads to radial vibrations. A practical example is a suction cup that sticks to a smooth surface because of both adhesion and a vacuum that is created when the air in the cup is pushed out. As tread blocks interact with some pavements, a similar effect can occur, generating sound. Figure 10 displays this effect (PIARC, 2013).



**Figure 10.** Stick-Slip mechanism between tyre-pavement (Sneaker Effect)  
Source: PIARC, 2013

When air is blown across the top of a bottle, a distinct tone can be heard. This occurs as the air in the neck of the bottle (acting as a mass) vibrates up and down on the pillow of air inside the bottle (acting as a spring). By itself, blowing creates very little sound. However, blowing across the bottle significantly amplifies the frequency that is distinct to that bottle (resonance). A similar effect can be found close into the wedge where the tyre and pavement meet. In this case, the mass and spring are side-by-side. The result is an amplification of some frequencies unique to the geometry of the tyre and the pavement. Figure 11 depicts the Helmholtz amplification mechanism (PIARC, 2013).



**Figure 11.** Helmholtz resonance amplification mechanism  
Source: PIARC, 2013

### 3. Rules, standards and guidelines

#### 3.1 Austria

In Austria, SMA designed to reduce noise are referred to as LSMA or SMA S3 according to the Guidelines for Planning, Construction and Maintenance of Roads, RVS 01.02.12 "Asphalt Technology" (FSV, 2011). The following two tables 1 and 2 specify the technical requirements for the asphalt mix SMA S3 and BTM in accordance with RVS 08.97.05 (FSV, 2010).

**Table 1.** Requirements SMA S3 (initial test) according to RVS 08.97.05 (edited by author), Source: BMVI, 2017

Mixture performance	SMA D S 3		
	Requirements for the initial test according to ÖNORM B 3584-1		
	SMA 8 S3	SMA 11 S3	Max. range
Binder sort	according to Annex 3, Table 9		
Stone material	according to Annex 2, Table 7 and 8		
Maximum grain size D [mm]	8		
Binder content [M.-%]	$B_{min5.4}$	$B_{min5.2}$	0,6
Additives	to be specified		
Additives [V.-%]	$V_{min6} / V_{max12}$	$V_{min6} / V_{max12}$	4
Wheel tracking [%]	PRD <sub>air5,0</sub>		
Binder drainage [%]	$D_{0,6}$		
Reaction to fire	ÖNORM B 3584-1, Table 12 - for use in enclosed spaces		
Sieve size [mm]	Requirements for the grading curves for the initial test and the declaration of conformity [M.-%]		
	SMA 8 S3	SMA 11 S3	Max. range
16		100	12
11,2	100	90 to 100	12
8	90 to 100	37 to 58	12
5,6			12
4	23 to 43	22 to 38	12
2	20 to 35	20 to 35	12
1	to be specified	to be specified	
0,5	9 to 24	9 to 24	12
0,25	to be specified	to be specified	
0,063	5,0 to 9,0	5,0 to 9,0	4

With the corresponding cross-reference in the requirements tables of RVS 08.97.05 (FSV, 2010), different binder systems are applicable. These requirements for the binder can be taken from Table 3 (BMVI, 2017).

**Table 2.** Requirements BBTM (initial test) according to RVS 08.97.05 (edited by author), Source: BMVI, 2017

Mixture performance	BBTM		
	Requirements for the initial test according to ÖNORM B 3581		
	BBTM 5A	BBTM 8B	Max. range
Binder sort	according to Annex 3, Table 9		
Stone material	according to Annex 2, Table 7 and 8		
Maximum grain size D [mm]	5		
Binder content [M.-%]	$B_{min5.4}$	$B_{min5.2}$	0,6
Additives	to be specified		
Additives [V.-%]	$V_{min11} / V_{max15}$	$V_{min11} / V_{max15}$	4
Wheel tracking [%]			
Binder drainage [%]			
Reaction to fire	ÖNORM B 3581, Table 8 - for use in enclosed spaces		
Sieve size [mm]	Requirements for the grading curves for the initial test and the declaration of conformity [M.-%]		
	BBTM 5A	BBTM 8B	Max. range
16			12
11,2		100	12
8	100	90 to 100	12
5,6	90 to 100		12
4		25 to 45	12
2	25 to 35	15 to 25	12
1	to be specified	to be specified	
0,5	8 to 18	6 to 16	12
0,25	to be specified	to be specified	
0,063	7,0 to 9,0	4,0 to 6,0	4

**Table 3.** Binder systems and their requirements according to RVS 08.97.05 (edited by author), Source: BMVI, 2017

Asphalt mix types, function and type <sup>1)</sup>																						
AC deck							AC binder		AC trag			BBTM		SMA		MA		PA				
A1	A2	A3	A4	A5	A6	A7	H1	H2	T1	T2	T3	5A	8B	S1	S2	S3	M1	M2	P1	P2	P3	P4
A	—	—	—	A	A	A	—	—	A	A	A	—	—	—	—	—	—	—	—	—	A	A
B	B	B	B	B	B	B	—	—	B	B	B	—	—	—	—	—	—	—	—	—	B	B
C	C	C	C	C	C	C	—	—	—	—	—	—	—	—	—	—	—	—	—	—	C	C
—	—	—	—	—	—	—	D	—	—	—	—	—	—	—	—	—	—	—	—	—	C	C
—	—	—	—	—	—	—	—	—	—	—	—	E	E	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	F	F	F	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	G	G	—	—	—	—
A							B			C		D		E		F		G				
—							—			—		—		—		—		20/30, ..., H				
50/70							50/70, ..., H			—		—		50/70, ..., H		50/70, ..., H						
70/100							70/100, ..., H			—		70/100, ..., H		70/100, ..., H		70/100, ..., H						
160/220							160/220, ..., H			—		—		—		90/10, ..., H						
—							PmB 25/55-65			PmB 10/40-60		—		PmB 25/55-65		PmB 25/55-65						
—							PmB 25/55-55			PmB 25/55-55		—		PmB 25/55-55		PmB 25/55-55						
—							PmB 45/80-65			PmB 45/80-65		PmB 45/80-65		PmB 45/80-65		PmB 45/80-65						
—							PmB 45/80-50			PmB 45/80-50		PmB 45/80-50		PmB 45/80-50		PmB 45/80-50						

H...Binder-modified additives are permitted (H stands for the name of the additive)

**3.2 Germany**

For semi-dense and dense road surfaces for noise reduction in Germany, the following regulations are to be consulted (Table 4). The wider selection of noise-reducing asphalt wearing courses compared to its neighboring countries is striking. Both basic parameters that affect the surface course are addressed, as well as specially created regulations for the corresponding construction method (BMVI, 2017).

**Table 4.** Overview of German regulations for noise-reducing asphalt wearing courses (edited by author), Source: BMVI, 2017

Low-noise asphalt wearing course	National regulations - Germany		
	Basic principles	Asphalt specific regulations	Physical properties and their influence
Noise-optimised asphalt concrete (AC D LOA)	R1: Zusätzliche Technische Vertragsbedingungen und Richtlinien für den Bau von Verkehrsflächenbefestigungen aus Asphalt (FGSV 799)	R2: Empfehlungen für die Planung und Ausführung von lärmtechnisch optimierten Asphaltdeckschichten aus AC D LOA und SMA LA (FGSV 739)	R2: Merkblatt zur Optimierung d. Oberflächeneigenschaften von Asphaltdeckschichten (FGSV 768)  W2: Arbeitspapier Textureinfluss auf die akustischen Eigenschaften von Fahrbahndecken (FGSV 442)
Low-noise Stone Mastic Asphalt (SMA LA)	R1: Zusätzliche Technische Vertragsbedingungen und Richtlinien für die Bauliche Erhaltung von Verkehrsflächenbefestigungen - Asphaltbauweisen (FGSV 798)	R2: Empfehlungen für die Planung und Ausführung von lärmtechnisch optimierten Asphaltdeckschichten aus AC D LOA und SMA LA (FGSV 739)	
Low-noise mastic asphalt (MA noise-reducing)	R1: Technische Lieferbedingungen für Asphaltmischgut für den Bau von Verkehrsflächenbefestigungen (FGSV 797)	R2: Empfehlungen für den Bau von Asphaltdeckschichten aus Gussasphalt (FGSV 740)	
Mastic asphalt with open-pored surface (PMA)	R1: Zusätzliche Technische Vertragsbedingungen und Richtlinien für die Bauliche Erhaltung von Verkehrsflächenbefestigungen - Asphaltbauweisen (FGSV 798)	W2: Arbeitspapier von Asphaltdeckschichten aus Gussasphalt mit offener Oberfläche (FGSV 738)	
Thin hot mix asphalt overlays on the road seal (DSH-V)	R1: Zusätzliche Technische Vertragsbedingungen und Richtlinien für die Bauliche Erhaltung von Verkehrsflächenbefestigungen - Asphaltbauweisen (FGSV 798)		

**3.3 Denmark**

In Denmark, after some quite extensive tests on single and double-layer OPA, investigations with SMA-like concepts were carried out in the EU project SILENCE (10). The SILENCE project was carried out from 2005 to 2008 by a very large research consortium consisting of 42 partners and had the task of examining almost all questions arising in connection with traffic noise in populated areas. This also included the optimization or redesign of noise-reducing asphalt wearing courses. The Danish partners designed 8 different, relatively fine-grained asphalt types with a maximum grain size of 4 or 6 mm and subjected them to a practical test. A selection was also tested in the vehicle-roadway test rig (PFF) of the BASt (German Federal Highway Research Institute). The result showed that high-cavity compositions (approx. 12 vol.%) led to low sound levels. Compared to a co-tested reference surface made of AC 11, level reductions of more than 4 dB(A) were achieved at 50 km/h (Ripke, 2011).

**3.4 Switzerland**

In Switzerland, so-called roughened asphalts (Macrorugueux) AC MR 4 or AC MR 8 are recommended according to Swiss standard SN 640 431-1b-NA (Asphalt mix- mix requirements - Part 1: Asphalt concrete) (DIN, 2013), whereby a distinction is made between a normalized and non-normalized solution. The latter has an increased void content of 10 to 14 vol.% in the finished layer, while the normalized solution reaches 6 to 10 vol.%. Although the asphalt type AC MR is referred to as asphalt concrete, the grading curves, with maximum proportions of coarse aggregates of up to 80 %, show an SMA-like concept, which, in combination with relatively low binder contents (≥ 5.8 wt.% for AC MR 8), leads to the above-mentioned high void contents.

Compared to SMA LA, the compositions are somewhat poorer in coarse aggregates and binders, but the path to surface courses with large roughness depths and plateau structure is comparable (Ripke, 2011). The requirements for AC MR 8 and AC MR 11 roughened asphalts are shown in Table 5.

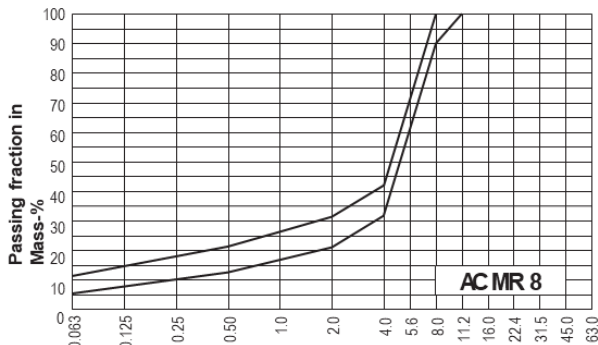
**Table 5.** Rough asphalt requirements AC MR (edited by author), Source: Prüflabor AG, 2020

Noise reduction gap graded asphalt AC MR							
Mixtures				Built-in layer			
Mixed material type	Binder-content [Mass-%]	Void-content VM [Vol-%]	Layer thickness [mm]	Air voids of Drill core [Volumen-%]		Degree of compaction [%]	
				EW	MW	EW	MW
Gap graded asphalt AC MR							
<b>AC MR 8</b>	≥ 5.8	3.0...6.0	25...40	2.5...8.0	3.0...7.0	≥ 97.0	≥ 98.0
<b>AC MR 11</b>	≥ 5.6	3.0...6.0	35...50	2.5...8.0	3.0...7.0	≥ 97.0	≥ 98.0

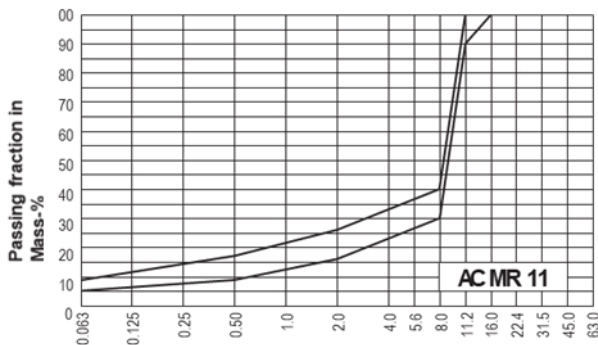
  

Requirements for the layer thickness		
	Single value/setpoint	Mean value/setpoint
Calculated mixture consumption	± 25 %	± 5 %
Layer thickness < 30 mm (Drill core) Layer thickness ≥ 30 mm (Drill core))	± 20 %	

The grading curve diagrams of AC MR 8 and AC MR 11 are shown in Fig.12 and Fig.13.



**Figure 12.** Grading curve diagram of AC MR 8 Source: Prüflabor AG, 2020



**Figure 13.** Grading curve diagram of AC MR 11 Source: Prüflabor AG, 2020

### Paving AC MR Mix

Do not pave when the temperature of the base is below +15 °C and during precipitation; profile differences and unevenness must be levelled out beforehand; avoid manual paving if possible; compaction with static smooth rollers ≥ 10 t; no rubber wheel rollers; do not release for traffic until completely cold. Only the AC MR Mix is not suitable for manual paving (Prüflabor, 2020). The asphalt wearing course AC MR is declared as asphalt concrete, but is characterised by maximum proportions (up to 80 %) of coarse aggregate. This corresponds roughly to a mixture similar to stone mastic asphalt (BMVI, 2017).

### Semi-dense mix in Switzerland (SDA)

Semi-dense asphalt (SDA) represents a new type of low-noise asphalt surface in urban areas. SDA with a maximum grain size of 8 mm is also used on motorways and has become the current standard pavement there. Alternatively, the new composition of maximum grain size and void content can be understood as semi-dense asphalt (SDA). In Switzerland, semi-dense asphalt with a maximum grain size of 4 mm (SDA 4) or 8 mm is used (SDA 8). Characteristic here is a void content which has a value between 12 and 20% by volume on the Marshall specimen (the void classes 12, 16 and 20% are common here, which are designated, for example, as SDA 4-12, SDA 4-16 and SDA 4-20). The upper void content range (20% by volume) is rather the exception. In western Switzerland, however, more cavity-rich variants of SDA 4 are very common (BMVI, 2017). Table 6 provides an overview of the Swiss regulations for noise-reducing asphalt wearing courses.

**Table 6.** Overview of Swiss regulations for noise-reducing asphalt wearing courses (edited by author), Source: BMVI, 2017

Low-noise wearing course	National regulations - Switzerland		
	Basic principles	Mixture specifications	Concept, execution and requirements for the installed layers
Semi-dens asphalt (SDA)	Requirements Aggregates Asphalts and surface treatments for roads, airfields and other traffic surfaces (SN 670 103b)	Semi dens mixture (SNR 640 436)	Rolled asphalt (SN 640 430)
Gap graded asphalt (AC MR)		Asphalt concrete (SN 640 431-NA)	
Mastic asphalt (MA)		Mastic asphalt (MA 640 441b)	Mastic asphalt (MA 640 440c)

Semi-dense mixes (SDA) are regulated by SNR 640 436 (Schweizer Norm SNR 640 436, 2015). This specifies requirements and instructions for design, production and implementation (Table 7). On the subject of the binder, only the use of polymer bitumen is permitted. Explicitly the grade PmB (CH-E) is recommended in this case. Irrespective of the void content, the binder content of an SDA 4 must not fall below a measured value of  $B_{min} \geq 6.0$  wt.%. For an SDA 8 the limit value is:  $B_{min} \geq 5.8$  M.-% (BMVI, 2017).

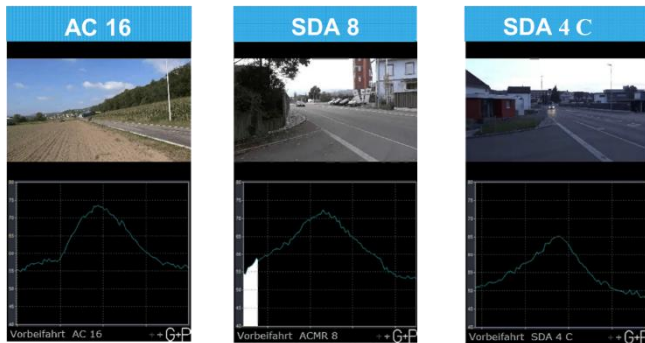
**Table 7.** Characteristic void content and void content limits of Marshall Specimens (SNR 640 436, 2015), *Source: BMVI, 2017*

Charakteristischer Hohlraumgehalt und Grenzwerte für den Hohlraumgehalt der Marshall-Prüfkörper Teneur en vides caractéristiques et valeurs limites de la teneur en vides des éprouvettes Marshall			
Sorte und Klasse Sorte et classe	- 12	- 16	- 20
	[Volumen-%] / [% volumique]		
SDA 4	12	16	20
SDA 8	12	16	
Grenzwerte für den Hohlraumgehalt der Marshall-Prüfkörper Valeurs limites de la teneur en vides des éprouvettes Marshall			
SDA 4	10...14	14...18	18...22
SDA 8	10...14	14...18	

Fig.14 shows the characteristics of low-noise pavements in Switzerland. Fig. 15 shows the comparison of pass-by speeds at 50 km/h on different pavements in Switzerland and Fig. 16 shows the visual difference between the surfaces of SDA 8 (left) and SDA 4 (right).

	PA Surface		
	PA 1	Semi-dense coverings	
	PA 1	SDA 8 / ACMR 8	SDA 4
Application	NS	NS, out of town, in town	In town
Sound absorption	large	medium	large
Characteristics	Pores throughout	Pores mostly not continuous	Micro pores
Water permeability	permeable	very low	impermeable

**Figure 14.** Properties of low-noise pavements in Switzerland (edited by author) *Source: Kanton Aargau, o.J.*



**Figure 15.** Comparison of pass-by speeds at 50 km/h on different pavements *Source: Kanton Aargau, o.J.*



**Figure 16.** Comparison between SDA 8 (left) and SDA 4 (right) *Source: Kanton Aargau, o.J.*

#### 4. Conclusion

Noise-reducing asphalt wearing courses are, by definition, asphalt wearing courses that lead to a reduction in tyre-road noise due to their surface texture. The generation mechanisms for the rolling noise can be traced back to two different physical causes:

- Mechanical excitation of the tyre by the road surface to vibrations;
- Aerodynamic processes in the tyre-pavement contact area;
- Favourable acoustic properties of road surfaces are based on two different mechanisms:
- Acoustically favourable roughness elements (texture) to minimize the mechanical excitations
- Cavities to absorb sound and avoid aerodynamic vibration excitation (air-pumping effect).

In Austria, SMA designed to reduce noise are referred to as LSMA or SMA S3 according to the Guidelines for Planning, Construction and Maintenance of Roads, RVS 01.02.12 "Asphalt Technology".

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