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Original Research Paper

Noise emission of concrete pavement surfaces produced by diamond grinding

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ABSTRACT

In Germany, diamond grinding is frequently used to improve the evenness and skid resistance of concrete pavement surfaces. Since diamond grinding has been observed to affect tyre/pavement noise emission favourably, the relationship among surface texture, concrete composition and noise emission of concrete pavement surfaces has been systematically investigated. The simulation program SPERoN was used in a parameter study to investigate the main factors which affect noise emission. Based on the results of the simulations, textured concrete surfaces were produced by using a laboratory grinding machine. As well as the composition of the concrete, the thickness and spacing of the diamond blades were varied. The ability of the textured surfaces to reduce noise emission was assessed from the texture characteristics and air flow resistance of textured surfaces measured in the laboratory. It was found that concrete composition and, in particular, the spacing of the blades affected the reduction in noise emission considerably. The noise emission behaviour of numerous road sections was also considered in field investigations. The pavement surfaces had been textured by diamond grinding during the last years or decades. The results show that diamond grinding is able to provide good, durable noise-reducing properties. Several new pavement sections were investigated using thicknesses and spacings of the blades similar to those used in the laboratory to optimize noise emission reduction. It is concluded that diamond grinding is a good alternative to exposed aggregate concrete for the production of low-noise pavement surfaces.

1. Introduction

The surface texture of road pavement significantly affects the emission of tyre/pavement noise. It affects both the vibrations of tyres and the aero-dynamic processes occurring between the tyres and the pavement surface that lead to noise emission. In Germany, diamond grinding has been used successfully for many years to improve skid resistance and the evenness of concrete pavement. It was observed that grinding

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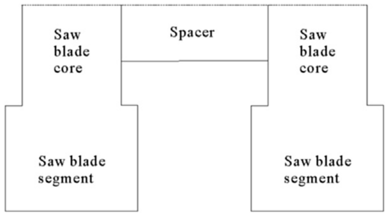

Fig. 1 – Typical configuration for grinding.

also has a favourable effect on noise emission. However, up to now it is not known which textures produced by grinding are particularly suitable for noise reduction. The effect of various parameters on the textural properties of concrete pavement surfaces produced by grinding and the resulting noise levels have been studied in a research project (Villaret et al., 2013). The research project was performed in cooperation between the engineering company Villaret Ingenieurgesellschaft, the TU München and Müller-BBM. The most important results of the project are presented here.

2. Grinding and grooving

Diamond ground texture is produced by running a series of saw blades which are gang-mounted on a drive shaft over the concrete surface. The depth of grinding is between 3 and 5 mm. Diamond-tipped grinding segments, variable in width, are situated at the edge of the blades. The separation of the blades is set by spacer disks and is at most 3 mm, which is shown in Fig. 1.

Diamond ground texture consists of grooves and land areas, i.e. the regions between consecutive grooves. The width of the grooves is determined by the width of the segments and the width of the land areas by the separation of the segments determined by the spacer thickness. Fig. 2 shows a cutting head and a typical surface texture.

Grooving is also produced by using running diamond grinding blades on a rotating drive shaft over the pavement surface. In contrast to grinding, the blades are separated by more than 10 mm. This method is primarily used to improve the water drainage of pavement surfaces. Fig. 3 shows a diamond grooved texture.

In USA, diamond grinding and grooving are used for other purposes besides the improvement of pavement evenness and skid resistance. Specially designed cutting heads are used

Fig. 3 – Diamond grooved texture (source: Otto Alte-Teigeler GmbH).

to texture the surface of city roads. These surfaces are particularly suitable for recreational activities such as bike riding or roller skating. Fig. 4 compares a diamond ground texture for city roads with a conventional texture.

Moreover in the United States, a special type of surface is used to reduce noise emission, the so-called Next Generation Concrete Surface (NGCS) which currently provides the best noise reduction for concrete pavement (Scofield et al., 2010). The production of NGCS consists of a combination of diamond grinding with minimum separation of the segments and conventional grooving. Fig. 5 shows the cutting head and the produced NGCS.

The NGCS can be applied to both newly constructed and existing pavement. Up to now, neither NGCS nor diamond ground texture for city roads has been used in Germany. Diamond grinding is mainly used to improve the skid resistance and evenness of concrete pavement for autobahns.

3. Diamond grinding in Germany

In Germany, diamond grinding has been used successfully for many years to improve skid resistance and the evenness of concrete pavement (Fig. 6). In this case, blade segments 3.2 mm in width with a spacing of 2.2 mm are mainly used. In the past, cutting heads with 80 cm–100 cm in width were used for producing diamond ground texture. Modern cutting heads currently possess a working width of 140 cm. The

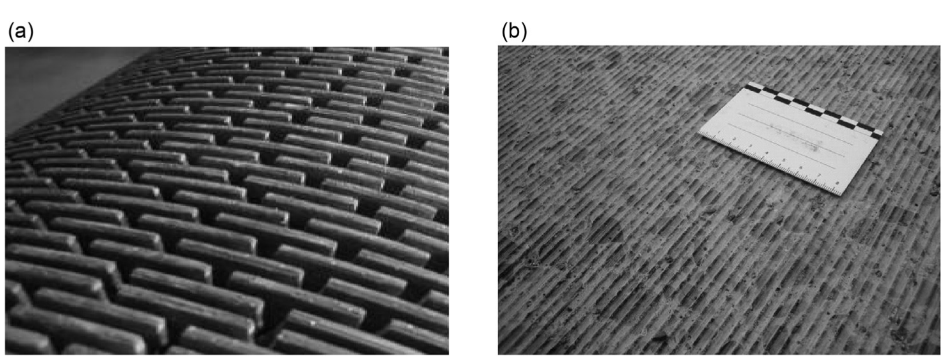

Fig. 2 – Cutting head and typical surface texture. (a) Grinding head. (b) Typical diamond ground texture.

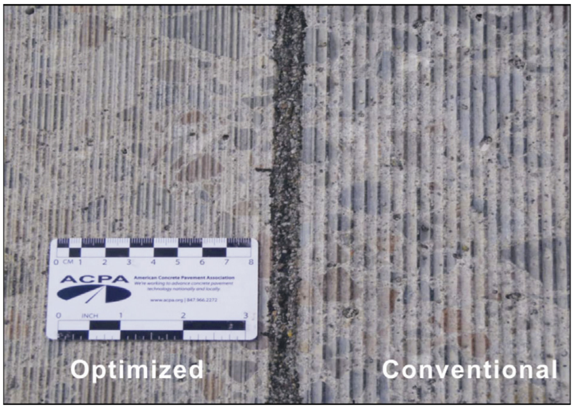

Fig. 4 – Diamond ground texture for city roads with conventional texture (Frantress, 2013).

Fig. 6 – Diamond grinding in Germany.

larger width increases performance and the number of joints between the grinding tracks. Overlapping areas are reduced which, in the past, often produced an uneven surface appearance and thus poorer noise reduction. The cutting head is driven by a 338 kW motor. Several sensors continuously monitor the height of the head in order to guarantee the desired flatness of the surface. To prevent floating at high feed rates, the machine must transfer sufficient weight to the cutting head. The grinding slurry is extracted by suction directly in the region of the cutting head and removed by a vacuum truck. Thus additional cleaning is not necessary and the road may immediately open for traffic after grinding.

4. Investigations on noise characteristics of existing surfaces produced by diamond grinding

In 2010, 2011, different autobahn sections with concrete pavement were investigated by the Federal Highway Research Institute (BASt). Because of evenness and skid resistance deficits, the pavement surfaces of these specific sections had been diamond ground in the context of a maintenance procedure. To investigate the noise-reducing potential the acoustic properties were determined with the statistical pass-by (SPB) method and close proximity (CPX) method. The results of the middle sound level of vehicle pass-by with a vehicle speed of 120 km/h detected with the SPB method are illustrated in Fig. 7. In comparison to the reference value for the sound level of vehicle pass-by of 85.2 dB(A) according to RLS-90 (1992) the measured autobahn sections show a noise-reduction of 2.4–3.0 dB(A).

With the CPX method, three autobahn sections over a distance of approximately 2500 m had been investigated according to their acoustic properties (Table 1). For that matter with an interval of 20 m the A-evaluated levels of acoustic pressure had been measured and averaged. The measurements take place at a speed of 80 km/h using two reference tyres.

The tyre CPX_P (passenger cars) is very well suited for evaluating the acoustic quality of the surface texture. The tyre CPX_P represents a similar behaviour as a conventional vehicle tyre.

The tyre CPX_H (heavy cars) is proportionally non-sensitive according to texture differences of the road surface but reacts sensitive to the absorption capacity and porosity of a surface. The tyre CPX_H represents a similar behaviour as a conventional truck tyre.

The measured data show that the CPX_P data are all contiguous between 96.2 dB(A) and 96.3 dB(A). For the CPX_H data acoustic pressure between 97.8 dB(A) and 97.9 dB(A) have been measured. In connection with an internal research project of the Federal Highway Research Institute (BASt), a multiplicity of exposed aggregate concrete surfaces has been

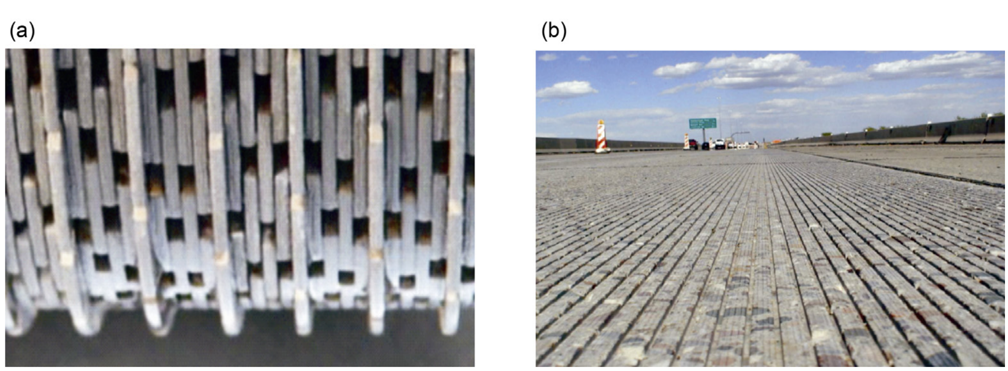

Fig. 5 – Cutting head and produced NGCS. (a) Cutting head for NGCS (for a single pass operation). (b) NGCS texture (IGGA, 2014).

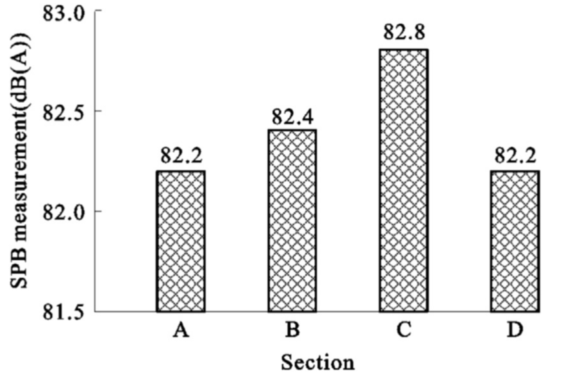

Fig. 7 – SPB measurements of surfaces produced by diamond grinding (BASt).

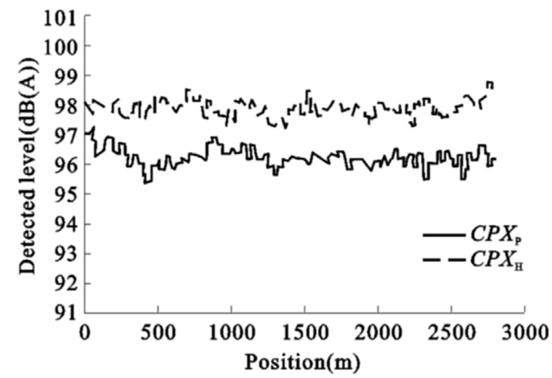

Fig. 8 – Detected levels of acoustic pressure (section D).

investigated according to their surface characteristics. The median of all exposed aggregate concrete sections is 97.4 dB(A) for the vehicle tyre and 97.2 dB(A) for the truck tyre. Fig. 8 shows exemplarily for section D the detected levels of acoustic pressure over the entire section length of 2500 m. Hardly, any spreading of the measured data is ascertainable. The standard deviation is 0.3 dB(A), which shows that the road surface of this section is very homogeneous.

Beyond that and in connection with the research of Villaret et al. (2013) further grinding sections different ages have been investigated in addition of their road surface characteristics. The following list contains the results of skid resistance measurements with the SKM method. The measurements have been done at a speed of 80 km/h. The age of grinding varies between one and ten years.

For newly built pavement, the minimum required level of skid resistance is 0.46 measured at a speed of 80 km/h. At the end of the period of warranty, the minimum required level is 0.40. All in all the investigated sections exhibit a high level of skid resistance in Table 2. The results of the researches prove the obvious noise reduction potential of grinding surfaces especially against the background of a permanent noise reduction.

In connection with further research activities, it has to be investigated how this potential can be utilized to a maximum at new construction and pavement reconstruction projects respectively. During the last years testing sections with new developed grinding patterns have already been diamond ground and acoustically measured. One example is a section at autobahn A 94 from Munich to Passau with a total length of 2000 m. In the summer of 2011, two parts of this section were textured by diamond grinding. In travel direction to Passau, the groove width (segment width) was 2.8 mm and in travel direction to Munich 3.2 mm. The space between the grooves (land area) was 2.2 mm for both directions. In 2012, the Federal Highway Research Institute (BASt) has executed SPB and CPX measurements which are shown in Figs. 9 and 10.

In comparison to the reference value for the sound level of vehicle pass-by of 85.2 dB(A) according to (RLS-90, 1992) both sections show a noise reduction of 1.5–3.1 dB(A). However the grinding texture with narrower groove width of 2.8 mm shows clearly lower levels of acoustic pressure in comparison to the section with a groove width of 3.2 mm. This tendency has been reinforced through CPX measurements. The CPX measurements with the vehicle tyre show that the section with narrower groove width has lower levels of acoustic pressure than the section with the higher groove width. Within the monitoring framework the autobahn A 94 is being investigated in frequent intervals. In 2014, new measurements are being planned.

The research of existing surfaces produced by diamond grinding shows that this texturing method is generally qualified to achieve a very durable long-life surface combined with an obvious noise reduction. Admittedly at the moment, this texture regulates freely according to different boundary conditions such as concrete composition, spacing and width of the diamond blades, the vibration characteristics of the diamond blades etc. In addition, environmental impacts and traffic change the texture, and accordingly change the acoustic properties and skid resistance.

5. Laboratory investigations

For the laboratory experiments, a grinding machine was designed with the blades and spacers used in field practice. The grinding machine is able to texture the surface of small

Table 1 – CPX measurements on grinding surfaces (80 km/h).

Section	CPX_P (dB(A))	CPX_H (dB(A))
A	96.2	97.9
B	96.3	97.8
D	96.2	97.9

Table 2 – Skid resistance measurement of diamond ground surfaces (BASt).

Autobahn	Year of grinding	Age of grinding (year)	μ_{SKM}
1	2010	1	0.84
2	2006	5	0.57
3	2009	2	0.71
4	2009	2	0.57
7	2005	6	0.63
24	2001	10	0.66
115	2004	7	0.55

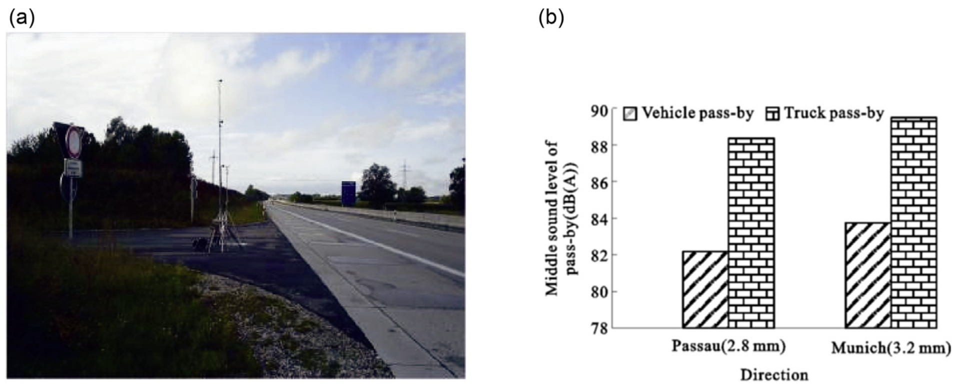

Fig. 9 – Test field and test results by SPB. (a) Section A 94 near Forstinning. (b) Results of SPB measurements.

concrete specimens, thus enabling easy variation of numerous parameters, such as the distance between the blades. Fig. 11 shows the laboratory grinding machine developed for the project.

Up to seven grinding blades may be placed on the drive shaft. The blades and spacing disks are 350 and 200 mm in diameter, respectively, corresponding to the cutting heads used in field practice. The cutting head is driven by an electric motor with a power of 2200 W enabling grinding up to depths of 10 mm at 2800 UPM. Each concrete specimen is mounted on a movable table underneath the cutting head. In order to texture a specimen, the cutting head is first lowered by hand to the desired depth of grinding which is adjusted to within one tenth of a millimetre. Then the table with the specimen is drawn across the cutting head manually via a spindle to produce the first texture track. The table is then laterally displaced (also to within one tenth of a millimetre) by the width of the texture track and the next track cut. The dimensions of the specimens textured in the laboratory experiments are 400 mm × 400 mm x 90 mm.

At first, the laboratory tests were carried out using mortar specimens in order to achieve an even surface and exclude the effect of the coarse aggregate on the texture. In the first part of the laboratory investigations, the thickness of the spacers was varied to determine their effect on texture geometry and therefore noise emission. The spacers were between 1.0 and 20.0 mm in thickness. The width of the grinding segments was kept at 3.2 mm and grinding was performed to a depth of 3 mm. Fig. 12 shows the texture of the mortar specimens.

Spacer widths of 1.0–2.0 mm result in very thin, well-defined fins with a low height instead of higher land areas because mortar is continuously removed between the grinding segments on account of their small separation. As the spacer width increases, less mortar is removed between the segments. At a spacer width of 3.0 mm, land areas remain which are very irregularly fractured. The height of the land areas corresponds to the grinding depth of 3.0 mm only at a few points. For spacer widths of 5.0 mm and above, the mortar between the segments is no longer removed. Intact land areas are produced whose height corresponds to the grinding depth. In order to quantify texture depth, a laser device for the determination of the estimated texture depth (ETD) according to EN ISO 134731 was used (IWS, 2014), as shown in Fig. 13(a). The ETD value is comparable to the MTD value determined with the sand-patch method. The results are shown in Fig. 13(b).

As mentioned above, the texture depths for spacer widths up to 3.0 mm are very small owing to the abrasion of mortar between the segments. The ETD value is between 0.31 mm ($d = 1.0$ mm) and 0.43 mm ($d = 3.0$ mm). For a spacer width of 5.0 mm, the ETD value is significantly higher because no mortar is removed between the segments during the grinding process. Thus the height of the land areas corresponds to the depth of grinding. For spacer widths of 5.0 mm and above, the

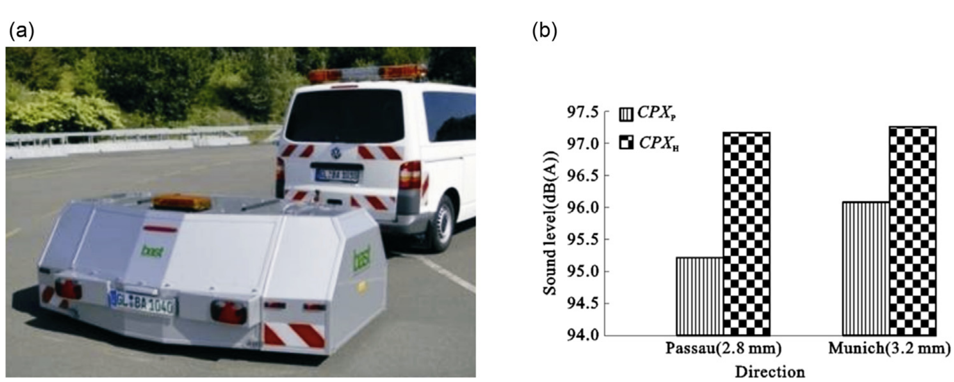

Fig. 10 – CPX-trailer and test results by CPX. (a) CPX-trailer. (b) Results of CPX measurements.

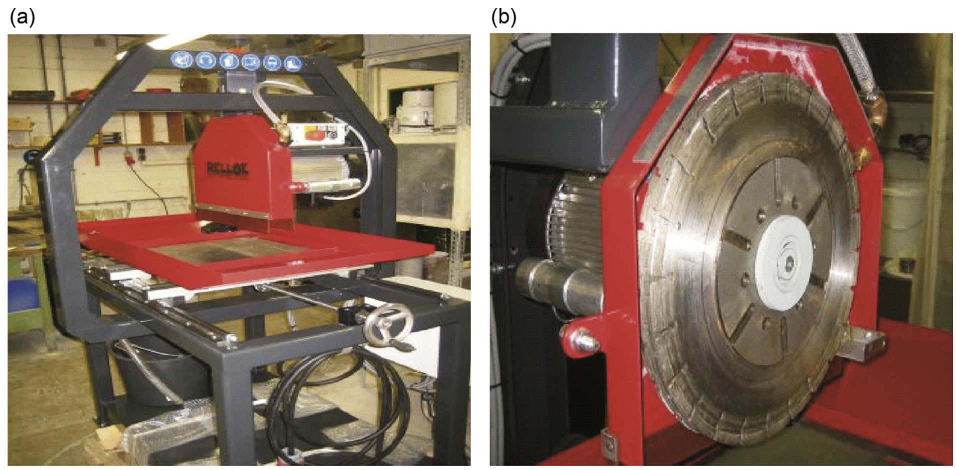

Fig. 11 – Laboratory grinding machine. (a) Bench. (b) Machine.

ETD value decreases because of the wider land areas. To assess the noise reducing properties of the surfaces, the surface texture was determined using a laser profilometer, which is shown in Fig. 14. Based on DIN EN 29053, the air-flow resistance of the surfaces induced by the texture was also measured.

Based on the results of these measurements, the expected noise produced by the surfaces was predicted with the SPERoN model. SPERoN (Statistical Physical Explanation of Rolling Noise) is a tyre/pavement noise modelling framework developed over the past decade with the purpose of predicting the effect of road properties on tyre/pavement noise. The

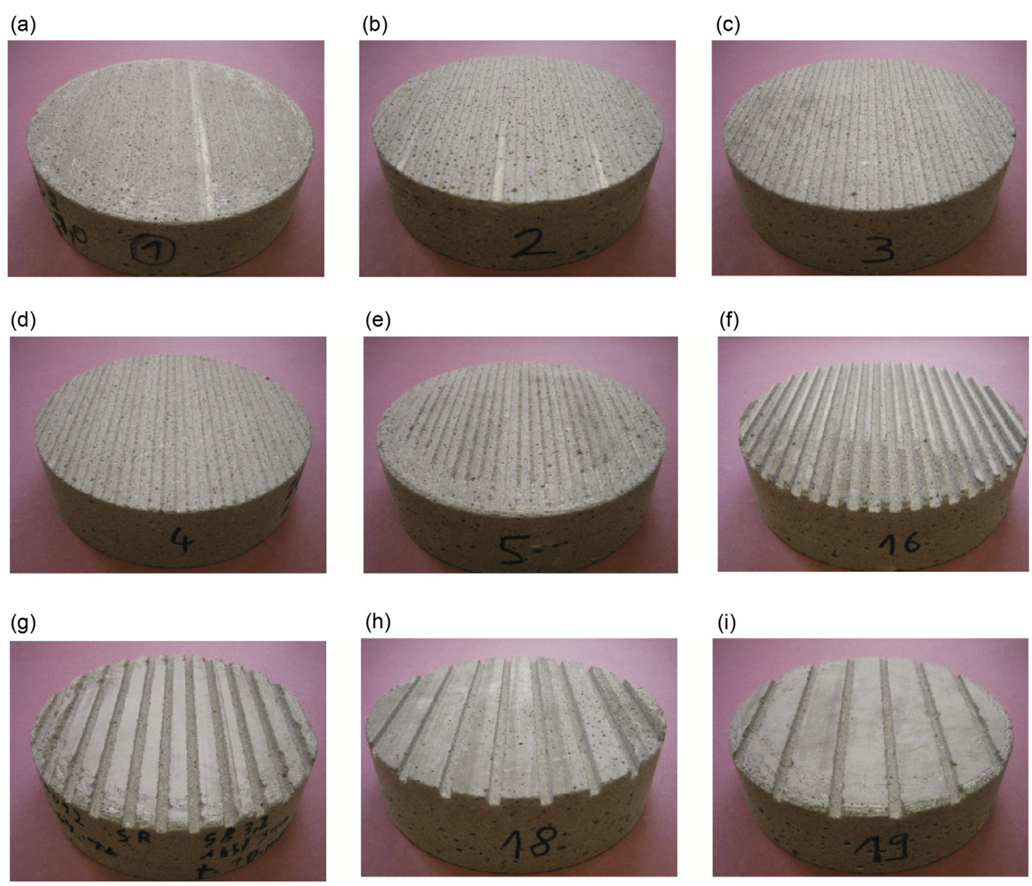

Fig. 12 – Drill cores of mortar specimens with varying thicknesses of spacers d. (a) $d = 1.0$ mm. (b) $d = 1.5$ mm. (c) $d = 2.0$ mm. (d) $d = 2.5$ mm. (e) $d = 3.0$ mm. (f) $d = 5.0$ mm. (g) $d = 10.0$ mm. (h) $d = 15.0$ mm. (i) $d = 20.0$ mm.

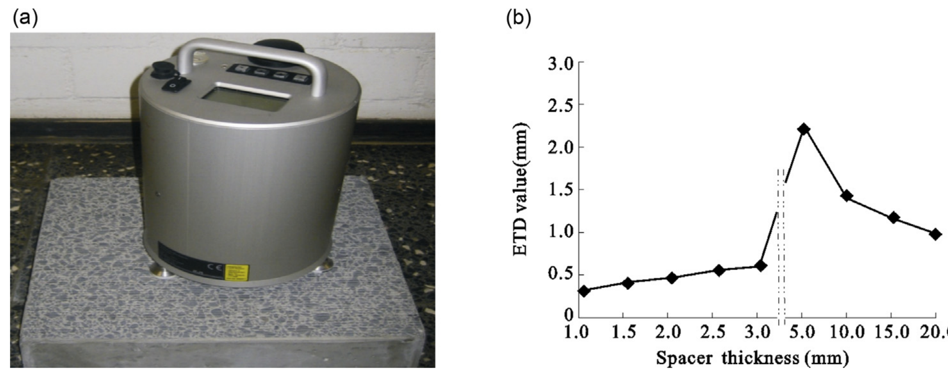

Fig. 13 – ETD test and test results (Segment thickness is 3.2 mm). (a) Laser device ELAtextur® to determine ETD value. (b) ETD values for diamond ground mortar specimens.

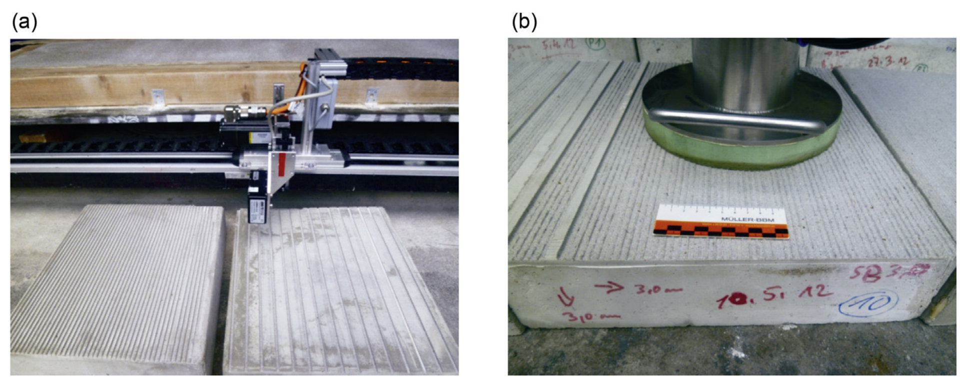

Fig. 14 – (a) Texture measurements and (b) measurements for texture-induced flow resistance.

SPERoN model calculates the coast-by noise of a vehicle by adding up four incoherent sound sources, i.e. tyre vibration p_1^2 aerodynamic sound sources p_2^2, tyre cavity modes p_3^2 and residual sound sources p_4^2 describing mainly the aerodynamic noise around the car body, which is shown in

$$p^2 = p_1^2 + p_2^2 + p_3^2 + p_4^2$$

The sound pressure level L is calculated from the surface texture and texture-induced flow resistance. L is the expected level of coast-by noise at a receiver point at a distance of 7.5 m from the center of the lane under investigation and a height of 1.2 m above ground. The calculated levels are similar to the results of SPB measurements, but it should be kept in mind that engine noise is not considered in the SPERoN model and

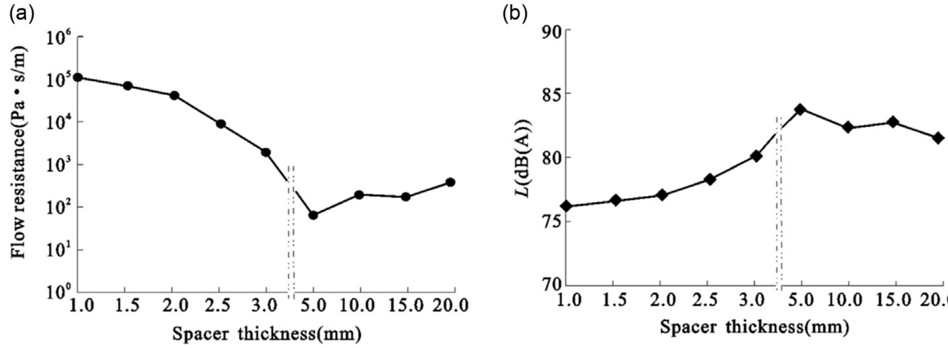

Fig. 15 – Flow resistances and calculated sound pressure levels for mortar specimens (Segment thickness is 3.2 mm). (a) Flow resistance. (b) Sound pressure level *L*.

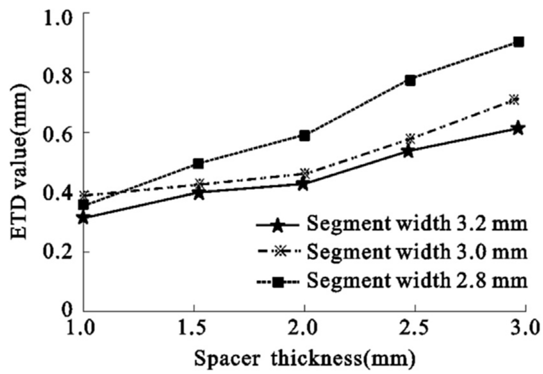

Fig. 16 – Effect of spacer thickness on ETD values of mortar specimens.

Table 3 – Composition, compressive strength and air void content of the concretes.

	Exposed aggregate concrete	Astro turf concrete	Subconcrete
Cement content (kg/m^3)	430	340	340
Cement type	CEM I 42.5 N	CEM I 42.5 N	CEM I 42.5 N
W/C	0.42	0.45	0.45
Aggregate 0/2 mm (kg/m^3)	423	500	500
Aggregate 2/8 mm, crushed (kg/m^3)	1277	–	–
Aggregate 2/16 mm, crushed (kg/m^3)	–	1455	–
Aggregate 2/16 mm, rounded (kg/m^3)	–	–	1455
Air void content (vol.%)	6.5	4.5	4.5
Compressive strength with 28d (MPa)	47.4	58.2	45.0

that the model has not been validated for anisotropic (different in the longitudinal and transverse directions) surfaces. Fig. 15 shows the texture-induced flow resistance and the calculated sound pressure level L for different spacer thicknesses. The sound pressure levels were determined for the tyre Michelin Energy 3 A with a width of 195 mm and at a speed of 120 km/h.

The flow resistance decreases with increasing spacer width up to 5.0 mm because the texture becomes more distinct enabling the air to escape with more ease. The lowest flow resistance is for a spacer width of 5.0 mm. At larger spacer widths, the flow resistance increases because less grooves per unit area are available for the air to escape. The calculated coast-by noise level is also significantly affected by spacer width and correlates well with the flow resistance measured. The level of sound pressure clearly increases with spacer width up to 5.0 mm. This is because the aerodynamic contribution becomes larger due to the reduced flow resistance. For spacer widths of 5 mm and more, the noise level decreases because the flow resistance increases on the whole, i.e. less space is available for aerodynamic effects.

In the second part of the investigations, the effect of the width of the grinding segments on noise emission was tested. In addition to the 3.2 mm segment in the first part of the tests, segments were considered with widths of 3.0 and 2.8 mm. Spacers thicknesses of 1.0, 1.5, 2.0, 2.5 and 3.0 mm were used. The grinding depth was also 3.0 mm. The appearance of the texture produced by segment widths of 3.0 and 2.8 mm is essentially that for the segment width of 3.2 mm. The measured texture depth for different spacer thicknesses is shown in Fig. 16.

As observed for segment width 3.2 mm, the texture depth also increases with spacer thickness for segment widths of 3.0 and 2.8 mm, the increase in depth being largest for a segment width of 2.8 mm where the land areas are better formed. The measured flow resistances as well as the calculated sound pressure levels are plotted in Fig. 17.

The air flow resistance curves are almost identical for the segment widths of 3.0 and 3.2 mm. In the case of the segment width of 2.8 mm, the flow resistance is in general lower because the surface contains more grooves or the texture depth is greater. Consequently, air can escape more easily and the flow resistance decreases. As previously noted, the calculated sound pressure level significantly increases with decreasing flow resistance. The sound pressure is higher for a segment width of 2.8 mm because more grooves are present and the flow resistance is lower. The sound pressure levels are almost identical for the segment widths of 3.0 and 3.2 mm.

In the third part of the laboratory tests, diamond ground textures were applied to concretes produced with different

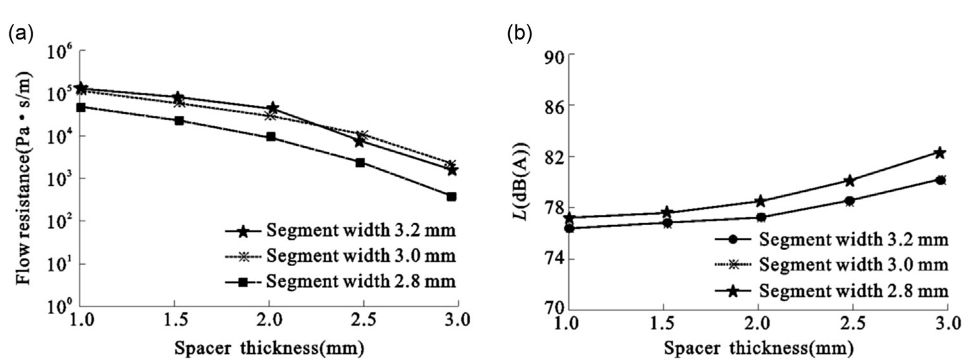

Fig. 17 – Comparison of flow resistances and calculated sound pressure levels for mortar specimens. (a) Flow resistance. (b) Sound pressure level L.

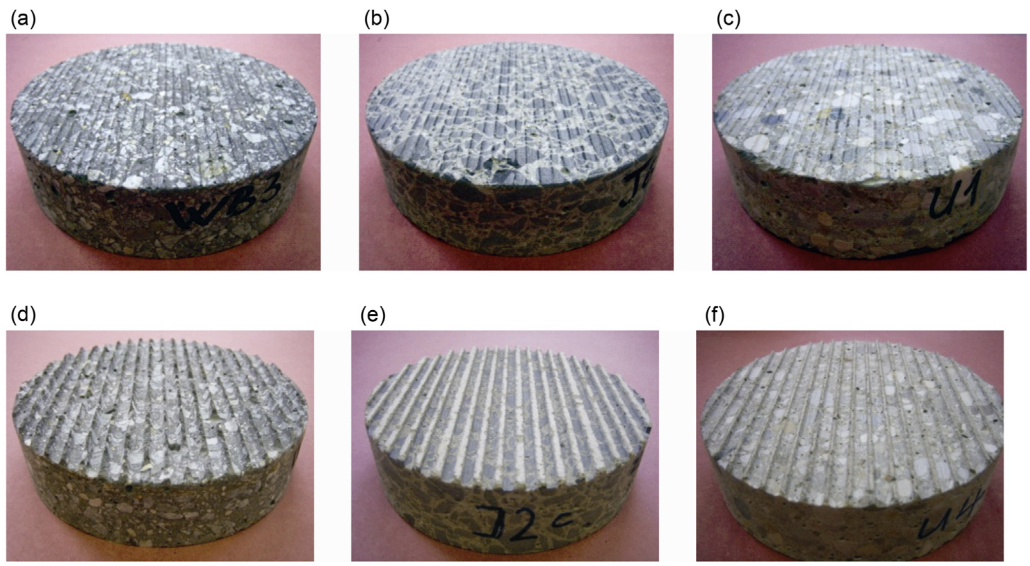

Fig. 18 – Drill cores of the diamond ground concretes with 2.0 and 5.0 mm spacer widths. (a) Exposed aggregate $d = 2.0$ mm. (b) Astro Turf concrete $d = 2.0$ mm. (c) Subconcrete $d = 2.0$ mm. (d) Exposed aggregate $d = 5.0$ mm. (e) Astro Turf concrete $d = 5.0$ mm. (f) Subconcrete $d = 5.0$ mm.

compositions in order to investigate the effect of concrete composition on the resulting texture and therefore noise emission. Specimens were prepared from a conventional exposed aggregate concrete and a concrete suitable for texturing with artificial turf as in field practice. In both cases, a crushed coarse aggregate was used. In addition, specimens were prepared from a concrete with rounded aggregate, as commonly used for subconcrete in road construction. This was to determine whether the use of smooth rounded aggregate (e.g. gravel) is, in principle, possible when the surface is textured by diamond grinding. The composition of the concretes and their compressive strength with 28 d are listed in Table 3.

The concrete surfaces were textured using spacer widths of 2.0 and 5.0 mm to determine the effect of concrete composition on diamond ground texture made with small and large spacer widths. In all cases, the width of the grinding segment was 3.2 mm and the depth of grinding 3.0 mm. As in the case of the mortar specimens, the textural properties and flow resistance were determined. To assess the skid resistance of the concretes, SRT values were determined with the SRT pendulum device (FGSV, 2004). Photographs of the concrete surfaces are shown in Fig. 18.

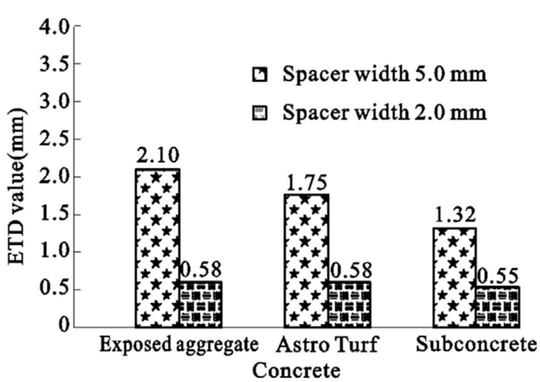

Fig. 19 – ETD values for concrete specimens.

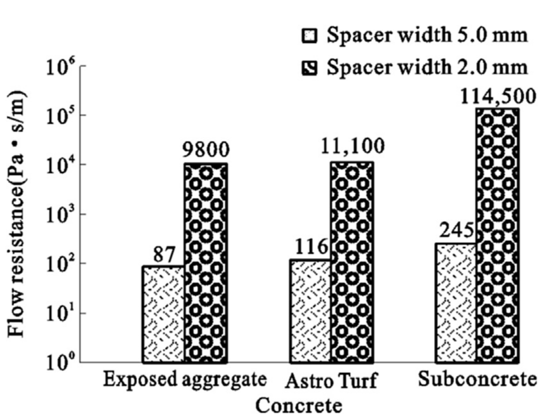

Fig. 20 – Flow resistances of concrete specimens.

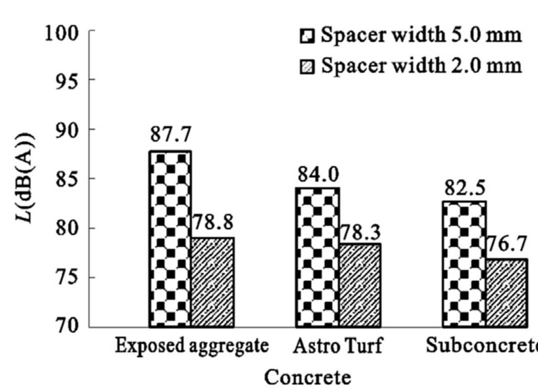

Fig. 21 – Calculated sound pressure levels for concrete specimens.

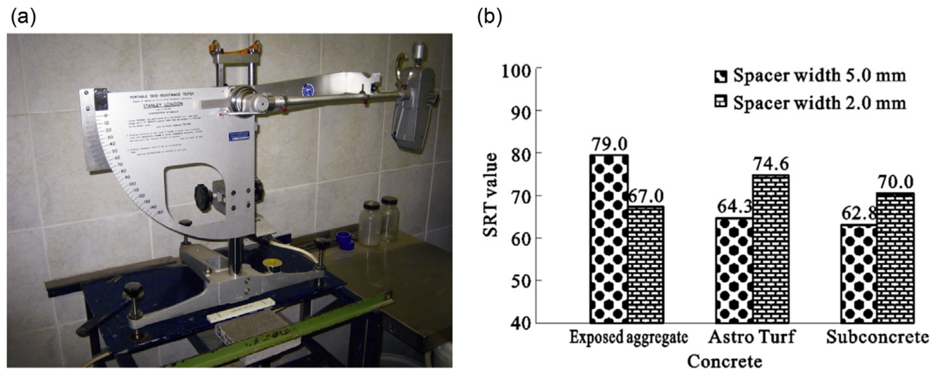

Fig. 22 – SRT pendulum and SRT values for concrete specimens. (a) SRT pendulum. (b) SRT values for concrete specimens.

Similar textures are produced with a spacer width of 2.0 mm. However, a distinct effect of concrete composition is apparent for a spacer width of 5.0 mm. In the case of exposed aggregate concrete, the land areas are unevenly fractured and very narrow. In contrast, the land areas of the concrete suitable for artificial turf texturing are wider and more homogeneous. The surfaces of the subconcrete and the exposed aggregate concrete are similar. The homogeneous land areas of the concrete for artificial turf texturing are presumably due to its compressive strength which is about 12 MPa higher than that of the other concretes. Higher compressive strength prevents breakage of the land areas during the grinding process. The photographs show that similar textures are produced on concrete with rounded (subconcrete) and crushed aggregate. Fig. 19 shows the texture depths measured for the concretes.

The texture depths of the concrete surfaces produced using a spacer width of 2.0 mm are similar; the ETD value is approximately 0.6 mm. The 5.0 mm spacer width results in a more pronounced texture which is therefore considerably deeper. Due to the very different shape of the land areas, the texture depths vary between 1.32 mm (subconcrete) and 2.10 mm (exposed aggregate concrete). Fig. 20 shows the flow resistances of the concretes.

Like the mortar, the concretes exhibit good agreement between texture depth and air flow resistance. Irrespective of spacer width, the concretes with the smaller texture depths possess the higher air flow resistance. Fig. 21 shows the calculated sound pressure levels.

As also observed for the mortar specimens, the sound pressure levels for a spacer width of 2.0 mm are much lower than with a spacer width of 5.0 mm. Here, there is a direct relationship between air flow resistance and sound pressure level. The concrete with the highest air flow resistance produced the least sound pressure. The results of the measurements of the SRT values are shown in Fig. 22.

For a spacer width of 5.0 mm, the SRT value of the exposed aggregate concrete is highest owing to the irregularly broken land areas. In the case of the concrete for artificial turf texturing and the subconcrete, the SRT values are lower for the 5.0 mm spacer width compared with the 2.0 mm spacer width because the fine roughness is lower. The SRT values

Table 4 – Concretes and textures of test section.

Concrete A			Concrete B			Concrete C		
10 m Texture 1	100 m Texture 2	100 m Texture 3	10 m Texture 1	100 m Texture 2	100 m Texture 3	10 m Texture 1	100 m Texture 2	100 m Texture 3

Table 5 – Composition of test section concretes.

Concrete	A	B	C
Cement content (kg/m^3)	340	420	420
Cement type	CEM I 42.5 N	CEM I 42.5 N	CEM I 42.5 N
W/C	0.45	0.45	0.45
Aggregate 0/2 mm (kg/m^3)	542	555	539
Aggregate 2/22 mm, crushed (kg/m^3)	1325	–	–
Aggregate 2/8 mm, crushed (kg/m^3)	–	–	1152
Aggregate 5/8 mm, crushed (kg/m^3)	–	1134	–
Air void content (vol.%)	5.0	5.5	5.5

Table 6 – Textures applied to concretes.

Texture	Grinding		Additional groove	
	Segment width (mm)	Spacing (mm)	Segment width (mm)	Spacing (mm)
1	2.4	1.8	2.8	22.8
2	2.4	1.8	–	–
3	2.4	1.5	2.8	21.0

(a) (b) (c)

Fig. 23 – Close looks of textures 1 to 3 (Concrete B). (a) Texture 1. (b) Texture 2. (c) Texture 3.

show that the fine roughness of the surface produced by the grinding process is similar for concrete containing rounded and crushed aggregate.

6. Test section

Based on the results of the laboratory investigations, an autobahn section was built in the federal state of Brandenburg (Germany) in September, 2014. The test section is 900 m long and divided into three sections made with different concrete compositions and textures as shown in Table 4.

The concretes differ in the cement content, the maximum aggregate size and the grading curve. Their composition is shown in Table 5.

Three different textures were applied to each concrete, as shown in Table 6. The textures were applied seven days after the concreting.

For conventional diamond grinding blade segments 3.2 mm in width with a spacing of 2.2 mm are used. Compared to the conventional configuration the segment width (2.4 mm) and the spacing (1.8 and 1.5 mm) used for textures 1 to 3 are lower. The laboratory investigations and the investigations in the field showed that a lower segment width and a lower spacing cause quieter surfaces. For textures 1 and 3 additional grooves were applied in order to investigate their effect on both skid resistance and noise emission. Close looks of the textures are shown in Fig. 23 using the example of concrete B.

Texture properties of the surfaces such as skid resistance and noise emission are being investigated. The test section will be monitored over the years to see how the properties develop.

7. Conclusions

The investigations in the field have shown that diamond grinding is a good alternative to exposed aggregate concrete for the production of low-noise pavement surfaces. With regard to the configuration of the cutting head with grinding segments and spacer disks, the noise emission was lower for segments widths of 2.8 mm than for 3.2 mm. In both cases the segments were separated by a distance of 2.2 mm.

The laboratory investigations have shown that noise emission is lowest for diamond ground concrete pavement surfaces produced with very low spacer widths. No effect of concrete composition on the textural properties was observed owing to the almost complete removal of surface material. The fine roughness of the surfaces was sufficiently high. However, it has not yet been determined whether the texture depths are sufficient for good skid resistance. Concrete composition has a significant effect on the geometry of the land areas when grinding is performed using larger spacer widths. In this case, the strength of the concrete had a decisive effect on the textural properties of the surface and thus noise emission. The concrete produced with rounded aggregate possessed similar textural properties, noise emission and fine roughness to concrete made with crushed aggregate.

Currently, a new research project focuses on the optimization of texture surfaces produced by diamond grinding with regard to noise reduction while ensuring a high level of skid resistance. Concrete compositions are being developed which are particularly durable regarding texture geometry. In addition, a laser device for controlling grinding machines is being developed to reduce overlapping areas and improve evenness.

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REFERENCES

FGSV, 2004. Arbeitsgruppe Fahrzeug und Fahrbahn: Technische Prüfvorschriften für Griffigkeitsmessungen im Straßenbau, Teil: Messverfahren SRT, Griff-StB (SRT). German test specification.

Frantress, D., 2013. Diamond Grinding Texture Options. North Dakota, Local Technical Assistance Program, Bismarck.

IGGA, 2014. NGCS Construction on Existing Roadways. Guide Specification, IGGA, West Coxsackie.

IWS, 2014. ELAtextur® for Measuring the Macrotexture of Pavements. IWS Messtechnik, Celle.

RLS-90, 1992. German Guidelines for Noise Abatement on Public Roads. Der Bundesminister für Verkehr, Bonn.

Scofield, L., Bernhard, R., Donavan, P., 2010. Development of the next generation concrete surface(s). In: 11th International Symposium on Concrete Roads, Seville, 2010.

Villaret, S., Altreuther, B., Beckenbauer, T., et al., 2013. Research Project FE 08.0211/2011/OGB Acoustic Optimization of Concrete Surfaces by Texturing of the Hardened Concrete with Improved Grinding Process. Federal Ministry of Transport, Building and Urban Development. Federal Highway Research Institute, Bergisch Gladbach.