Maintenance and Rehabilitation

Rehabilitation of porous low noise pavement by large-scale surface grinding

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Abstract

Low noise wearing courses are an effective measure to mitigate road traffic noise emission at its source. In Switzerland, a trend of using so-called semi dense asphalt (SDA) with porosity of 10 to 18% and a maximum grain size 4 or 8 mm has emerged about a decade ago. Despite the initial noise reduction values of -6 to -9 dBA, the acoustical and mechanical lifetime of such pavements remains below expectations. This acoustic ageing is dominated by clogging of the open pores and altering macro-texture due to ravelling. Our preliminary work on small test sections has shown that an accurate grinding of the surface is an effective way to regain up to -5 dBA in noise reduction. Depending on the state of clogging and extension of ravelling at the time of the maintenance, the program may require different intensities of grinding followed by sweeping and high-pressure washing. The purpose of this paper is to put forward a maintenance process that is effective to rehabilitate the acoustic performance of aged SDA wearing courses at large-scale. Two roads that were treated in 2018 with a grinding depth of 1.5 to 3 mm showed positive results with an average gain in noise reduction of -3 dBA, measured with the close-proximity (CPX) method. At each location, the treatment was evaluated by the measurements of grinding depth, CPX rolling noise and visualization of the clogged porosity. Performance of the grinding method depending on grinding depth and impact of the aggregate's petrography are discussed. Additionally, we monitored the long-term behaviour by sequential CPX measurements. Our first results indicate that the treated surface remains stable and noise level gains are preserved over the available time window of the initial 1-year monitoring phase.
Keywords: low noise asphalt; porous asphalt; grinding; CPX measurement
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1. INTRODUCTION

In Switzerland most of the low noise wearing courses are made of a semi-dense asphalt (SDA) with maximum grain size 4 and 8 mm and pore volume of 10% - 18%. They are commonly abbreviated as SDA 4 and SDA 8. According to the Swiss reference model for monitoring road noise levels [1], a list of the best low noise pavements [2] reveals that right after laying the acoustic gain (CPX, 50 km/h, car only) ranges between -6 and -9 dBA. After one year of traffic, the same pavements show that the initial low noise level can in most cases be maintained. In the following years the gain originally seen decreases, in some cases substantially, due to clogging of the interconnected pores and altering of the surface texture.

The clogging process has previously been described in [3][4][5]. The soiling is a mixture of loose sandy material and some finer mud, clay for instance. By filling the pores and the narrow channels between them it forms a dense and impermeable clogging barrier. Further, it has been shown for the SDA 4 type that soiling density and filling ratio of pores tend to decrease as a function of depth with a barrier layer at top and a layer of clean pores free from soiling at the very bottom.

Some road owners task the road construction companies to maintain a residual acoustic gain of at least -4 to -5 dBA after 5 years of use. Experience shows that without accurate maintenance activity, this requirement can only be met by approximately half of the projects. During the last decade, many experiences have shown that water-jet cleaning and suction is not an effective method to maintain or even regenerate a clogged porous wearing course [5][6]. It is thus time to move on to something else. Taking into account that most of the clogging material is present right below the surface, grinding provides the basis for a new promising approach. Our concept is to lightly grind off the upper surface giving two beneficial outcomes: the aged texture is restored and the clogged layer is partially removed at the same time.

For specific applications, such as increasing the skid resistance, grinding of the wearing course is already in practice in many countries. For others, such as restoring hydraulic conductivity [7], or, like our aim, in connection with noise recovery trials on dedicated test sections, have already been conducted [8]. The Swedish authors of the latter publication were principally seeking to optimise the pavement surface texture to reduce the tyre/road noise. They describe their procedure as “shaving off” the peaks in order to obtain a more “negative texture” which is generally known to have a positive effect on the acoustic performance. The method is not especially dedicated to porous low noise pavements nor to eliminate the clogged layer if any. For dense asphalt, the acoustic gain is less than -1 dBA. For porous asphalt, depending on the grinding depth and the state of clogging, the acoustic gain ranges between -0.6 and -3.3 dBA. Also, it must be noted that the study was done on wearing courses with maximum aggregate size of 11 to 16 mm and therefore differs substantially from the present work that is focused on the SDA 4 type.

In April 2018 we have treated and analysed a first set of small test sections in Switzerland [4]. In these tests CPX measurements were taken after grinding and have shown a significant improvement of the noise level of -3 to -4.5 dBA compared to the untreated reference. This acoustic regeneration was sufficient so that the local noise level on the test patches again conformed to the 5 years requirements of the road owner. Based on this positive outcome the experiments have been extended to much larger test sections in November 2018 (Fig. 1), with the focus on scaling-up the process to maintain entire low-noise road sectors in an economical manner.

The aim of this paper is to show feasibility of a large-scale maintenance process to regain satisfactory noise reduction on a small grained (max grain size 4 mm) porous pavement after a service life of at least 5 years. We will do this based on the overall results from the mentioned 2018 test sections and show the outcome in terms of grinding depth, on-the-go CPX measurements and first insight to the durability of the maintenance measure.

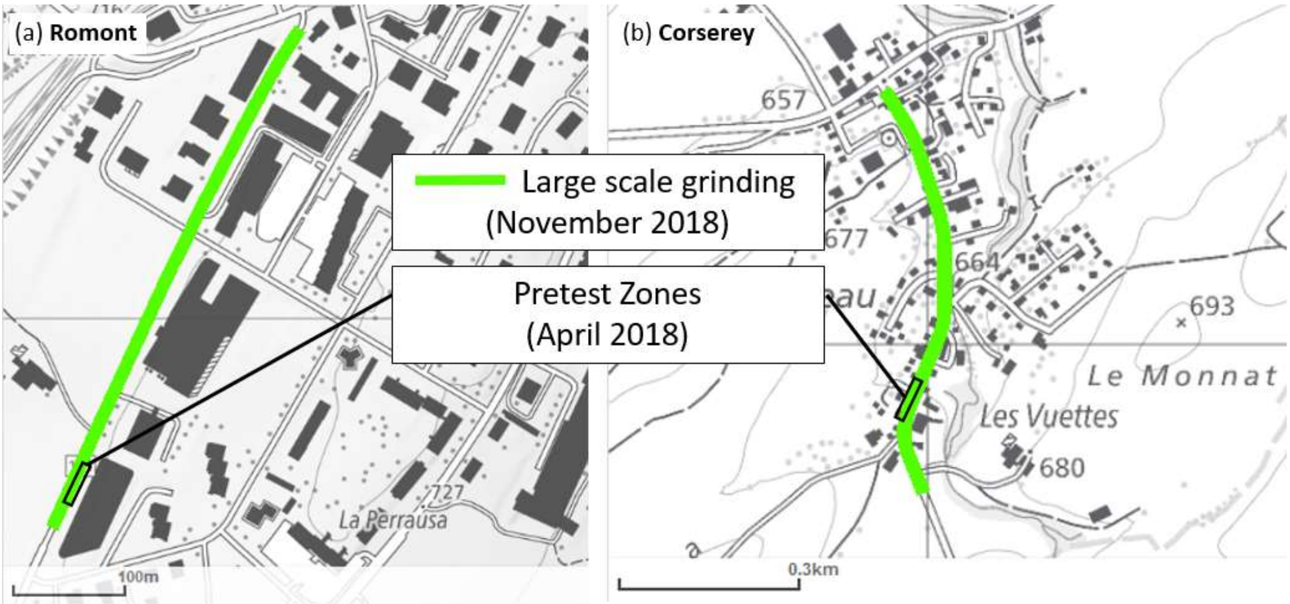


Fig. 1: Maps of the two test sections that were chosen for the large scale grinding procedure after successful pretests in smaller zones earlier in the same year.

2. MATERIALS AND METHODS

2.1. Test sections

The first road is situated in an industrial district with rather heavy traffic in the town of Romont (FR). The 535 m stretch of low noise pavement of type SDA 4 and approx. 18% pore content was laid in 2011 (Fig. 1a). The first trial of grinding work was done in April 2018 within two small subsequent zones of 20 m length each in one lane of the road. At that time, the pavement was 7 years old and showed substantial clogging and pop-outs in the wheel tracks. Later on in the same year the entire road stretch was treated by the up-scaled grinding process. Table 1 gives an overview of the different test sections and effective dimensions.

The second road is located nearby in the rural town of Corserey (Fig. 1b). It has less traffic but more intense agricultural activity than in Romont. The same type of low noise pavement is present but with a slightly lower porosity of 15%, which was laid in 2012 with a total length of 730 m. The same grinding scheme as in Romont was applied but with an extra section where the large-scale grinding was done twice (Tab. 1).

Table 1: Overview of test sections, worked length and area as well as individual treatment.

Road	Test Section	Length [m]	Worked Area [m^2]	Treatment
Romont (2011)	Pretest Zone 1	20	70	1 pass with small machine
	Pretest Zone 2	20	70	3 passes with small machine
	Large scale grinding	540	3600	1 pass with large scale machine
Corserey (2012)	Pretest Zone 1	20	60	3 passes with small machine
	Pretest Zone 2	20	60	10 passes with small machine
	Large scale grinding	730	4300	1 pass with large scale machine
	Section 2x grinding	70	210	2 passes, large machine, slowest speed

2.2. Grinding Work

The focus of this paper is the large scale process with the aim to show its potential as a real road maintenance procedure. For this, a Unimog truck with 5 HTC 950 floor grinding heads attached on a custom made rig to its front was used. The machine has an adaptable working width of 2.4 - 4.2 m (Fig. 2a) and normally it is employed to improve the skid resistance. We adapted grinding speed to 2-3 m/min, as a compromise for grinding depth and ability to treat the entire road in one working day. Behind the Unimog a convoy of 2 street cleaning machines followed to sweep up the debris from the grinding process and to perform a final cleaning of the surface with high pressure water (Fig. 2b to 2d).

For evaluation of the large-scale results the described small pretest zones are added to the data as a reference. The treatment applied in those sections is described in more detail in a preceding publication [4]. The main difference lies in a smaller grinding machine and especially in the number of passes (as stated in Tab. 1) applied in order to explore the effect of deeper grinding depths.

Fig. 2: Images of the large-scale grinding work. The lead vehicle (a) worked its way on the entire width of one lane. The grinding heads produced an even layer of fine-graded sand (b) that was cleaned up directly with two street cleaners (c). Behind this convoy the ground surface was directly ready for traffic.

2.3. Petrography of Road Materials

During the preliminary trials in April 2018 we observed that the grinding depth per pass was significantly different in Romont and Corserey. These findings pointed toward a need for a more detailed examination of the petrography of the aggregates. The result is shown in Table 2 with a clear difference between the proportions of hard, resistant rocks.

Table 2: Proportion of hard and soft rocks in the SDA 4 mixture for each road.

Road	**Grain size [mm]**	**4/6**	**2/4**	**1/2**	**Grinding depth per pass [mm]**
Romont	Proportion of hard, resistant rocks [mass %]	67.2	79.2	72.8	2.3
	Proportion of mid-hard and soft rocks [mass %]	32.8	20.8	27.2	
Corserey	Proportion of hard, resistant rocks [mass %]	93.8	90.9	78.8	1.0
	Proportion of mid-hard and soft rocks [mass %]	6.8	9.1	21.2	

2.4. Acoustic monitoring

Acoustic performance has been measured on the go with a CPX trailer [9]. The noise reduction is calculated relative to the Swiss reference level called StL86+ which depends on the type of vehicles (car vs. truck) and the speed [1]. Therefore, noise is measured with separate tyres at a speed of typically 50 km/h or 80 km/h. The two values CPX_{car} and CPX_{truck} are then mixed to reflect a standard real traffic with 10 % trucks called CPX_{mix}. The absolute accuracy of CPX measurement is within ±1.0 dBA but relative differences within the same test runs can be resolved at approx. ±0.2 dBA.

2.5. Grinding depth measurements

A simple method was used to determine the grinding depth through differential measurements from before and after grinding. A rigid metal bar was laid across the entire lane onto two supporting points that were not changed during grinding, then the distance from the bar to the road surface was measured with a ruler along the profile at spacing of 25 cm, resulting in an ensemble of 12-14 single point measures for one lane cross section. For an averaged cross-section, the accuracy of this method lies at about ±0.5 mm. The same procedure was repeated at multiple predefined locations along the worked area yielding spatially resolved grinding depth data.

2.6. Visualisation of the clogged porosity

To assess the state of clogging of the SDA, cores of diameter 150 mm are cut from the site. The porous layer is sawn from the rest of the core and sealed along the curved surface while the two flats remain accessible. An appropriate epoxy resin is coloured with fluorescent pigments and the SDA sample is fully vacuum impregnated from each side with different colours. After curing the specimen is sawn into two pieces to obtain a pair of sections. Finally, each section is photographed under UV light to reveal the UV fluorescent material filling the pores. The distinction between the two colours allows for qualitative visualisation of pore accessibility from the top and from below.

From each road, several cores have been impregnated. Some of them were cut from the pre-test Zone 2 and some from other places along the road where the large-scale maintenance took place. Overview of sampling time and location is given in Table 3.

Table 3: Overview of the cores taken from the roads in Romont (Ro) and Corserey (Co).

Reference 2018 before grinding	2018 / directly after grinding	2019 / 6-12 months after grinding		
	Zone 2	Zone 2	Large-scale maintenance	
Ro02	Ro08	Ro09	Ro12	Ro13
Co02	Co07	Co09	Co11	Co12

3. RESULTS AND DISCUSSION

3.1. Upscaling the process

A clear visual difference between ground and untreated surface can be observed visually (Fig. 3). The horizontal grinding removes the material top-down, leaving partially cropped grains embedded in the matrix. Also, the surface grip remains the same or becomes even better after grinding. This was measured and verified during the trials in April 2018 but not repeated for the large-scale process since the same machine and tools are normally used to improve skid resistance, though at much higher working speed. A traffic safety risk due to the grinding process can therefore be excluded.

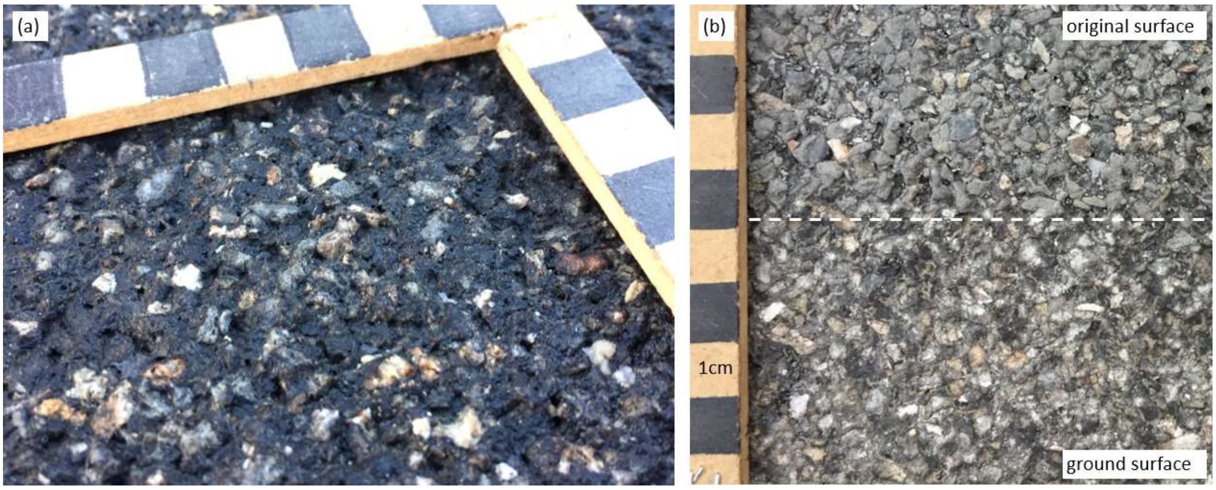


Fig. 3: Close-up images of the treated SDA 4 surface in (a) wet state directly after final cleaning and (b) in dry state with direct comparison to the untreated original surface.

Cleaning behind the grinding machine must also be understood as an important part of the entire maintenance process. Unlike in the pretrial, the large-scale treatment could not be done in entirely dry mode. Adding water in front of the big grinder was necessary to bind dust. The resulting moist layer of debris was much more difficult to clean up afterwards. Conceptually, it would be preferable to stay in a completely dry process in order to avoid risk of re-clogging the porous pavement by grinding. However, this compromise was taken in favor of demonstrating feasibility of a large-scale maintenance process. Deeper analysis of available and future data must show how much of an impact on the noise reducing effect the presence of water has.

3.2. Grinding versus petrography

By comparing the mean grinding depth per pass with the content of hard rocks from Table 2 it is evident that the petrography is affecting the ease of grinding. One could now argue that from a maintenance point of view a lower content of hard, resistant rocks may be beneficial in order to reach optimal depth in one pass, reducing working time of the convoy and minimising wear of the expensive tools. On the other hand, hard, resistant rocks are essential to ensure skid resistance on the long term. Also, it must be pointed out that the asphalt mixture used in Romont with less hard rock content still complies with the Swiss standards. Furthermore, the grinding process we used will forcibly improve the skid resistance, especially on roads where it has decreased over the years due to material composition. With this in mind, one could possibly aim for an asphalt recipe that strikes a balance between maintenance benefits and risks linked to a lower content of hard, resistant rocks. In any case, before defining the optimal content of hard rocks, the noise reduction potential of the grinding process in terms of grinding depth must be analysed and understood first.

3.3. CPX results

The CPX values from previous year 2017 and those carried out directly after grinding are compared to determine the absolute acoustic gain due to grinding. CPX_{car} varies between -3 and -5 dBA, depending on the test section, the grinding depth and the grinding machine (Table 5). It is with the deepest grindings that the best acoustic gains are achieved, but even with the large scale grinding and small grinding depths of only 1-2 mm, as in Corserey, a surprisingly large effect of approximately -3 dBA is provided. Generally, the preliminary tests showed better results than the large scale maintenance, even in case of a same grinding depth as in Romont Zone 1. Since the grinding tools were the same it could be the number of passes and the cleaning with water which may be responsible for the difference.

Table 5: Acoustic effect of grinding in relation to test section and grinding depth; immediate acoustic gain compared to the non-grinded surface.

Test sections	Grinding depth	Gain CPX_{car}	Gain CPX_{truck}
Romont	[mm]	[dBA]	[dBA]
Pre-test Zone 1	2-3	-4.6	-2.5
Pre-test Zone 2	4-7	-5.0	-3.4
Large scale maintenance	2-3	-3.2	-3.5

Corserey	[mm]	[dBA]	[dBA]
Pretest Zone 1	4-6	-3.5	-1.8
Pretest Zone 2	9-12	-4.7	-4.0
Large scale maintenance	1-2	-2.8	-3.2
Short section 2x grinding	2-3	-2.9	-3.6

Furthermore, noise has been monitored two times during the first year after April 2018, yielding data 6 and 12 months after grinding. The relative CPX values related to the Swiss reference level StL-86+ show some loss after 6 months but remain remarkably stable after that period of time for the pretest zones where the longer term data was already available (Table 6).

Table 6: Monitoring of acoustic effect after grinding for the different test sections; 6-12 months CPX-data in reference to Swiss StL-86+ level for car, truck and 10% mix separately.

Test sections	CPX_{car} / StL-86+ [dBA]			CPX_{truck} / StL-86+ [dBA]			CPX_{mix} / StL-86+ [dBA]		
Romont	initial	+6 mt	+12 mt	initial	+6 mt	+12 mt	initial	+6 mt	+12 mt
Pretest Zone 1	-4.7	-2.7	-2.9	-7.6	-6.3	-6.5	-6.1	-4.5	-4.7
Pretest Zone 2	-5.1	-2.7	-2.8	-8.5	-6.4	-6.7	-6.8	-4.6	-4.8
Large scale maintenance	-3.2	-2.6		-7.0	-6.6		-5.1	-4.6	
Corserey	initial	+6 mt	+12 mt	initial	+6 mt	+12 mt	initial	+6 mt	+12 mt
Pretest Zone 1	-4.1	-3.4	-3.3	-7.6	-6.8	-6.5	-5.8	-5.2	-5.0
Pretest Zone 2	-5.3	-3.0	-3.2	-9.8	-6.8	-6.5	-7.5	-4.9	-4.9
Large scale maintenance	-3.5	-2.5		-7.2	-6.1		-5.4	-4.3	
Short section 2x grinding	-3.6	-2.9		-7.6	-6.7		-5.6	-4.8	

Figure 4 provides the monitoring results for the past 8 years expressed in CPX_{mix} values averaged over the entire road section, which at the end is the relevant measure for the road owners. In the case of the Romont test section, grinding helped gain 3.2 dBA whereas in Corserey the immediate outcome is very similar with 3.0 dBA. For the latter, however, the loss after 6 months is nearly double, possibly due to the lower grinding depth, which was limited in this case by the higher content of hard rocks in the asphalt mixture.

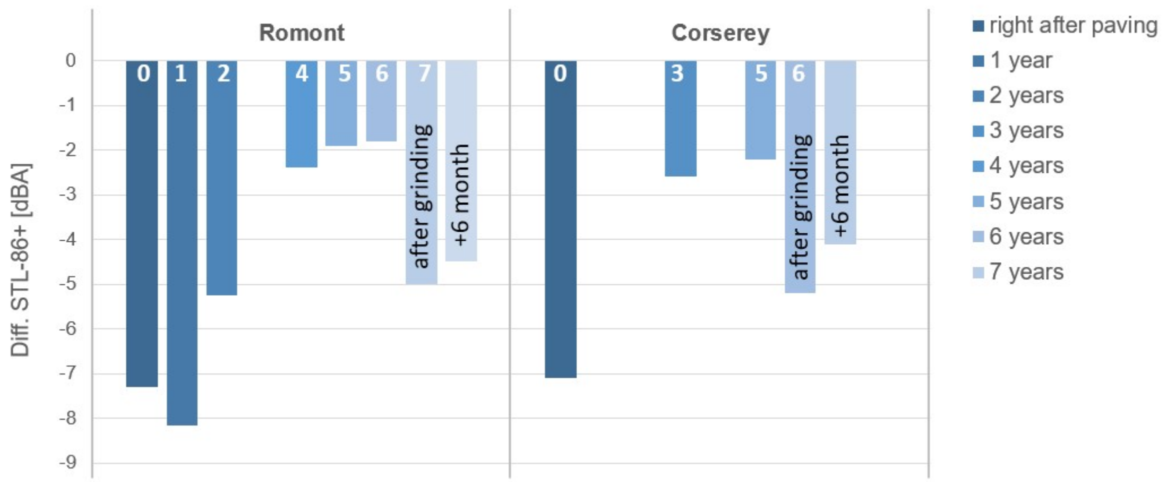


Fig. 4: Acoustic monitoring of the test sections in Romont and Corserey since construction of the low-noise pavement; CPX_{mix}-values.

Clearly, a one-year follow-up is still too short to evaluate the potential grinding has for the road authorities, especially from an economical point of view. But given, that after 6-12 month after treatment, the effect is still clearly measureable and the initial decay remains within moderate bounds, a durability of 2-4 years can be roughly assumed on basis of the current positive results.

3.4. Analysis of cross-sectional images

The image analysis was completed with the intent to visualise the state of clogging of the pores and how it is impacted by the maintenance action. Furthermore we can examine accessibility to the open pores in relation to the acoustic performance. To this end, the cross-sectional images from cores listed in Table 3 are shown in Figures 5 and 6 together with the CPX_{car} values measured within the same 10m-segment of each core at time of sampling.

Cores taken for reference before grinding show a mere situation of barrier right at the surface. The top surface is impervious to resin (Fig. 5 and 6, left images). One can conclude that the sound waves and pumping air from the rolling tyre are completely hindered to enter the absorptive material. This situation corresponds to a relative noise level of 0 dBA for the CPX_{car} value. Grinding off 4 to 12 mm – as it has been done in the Zone 2 from the preliminary tests – clearly provides access again to the unclogged pores beneath (Fig. 5, middle). With the barrier layer mostly gone the resin is able to penetrate the porous space from the top, which relates to an acoustic improvement of more than -5 dBA. Then during the following months partial clogging occurs and the cores taken one year later show that the ingress of resin became more difficult (Fig. 5, right side) and the noise reduction has decreased again.

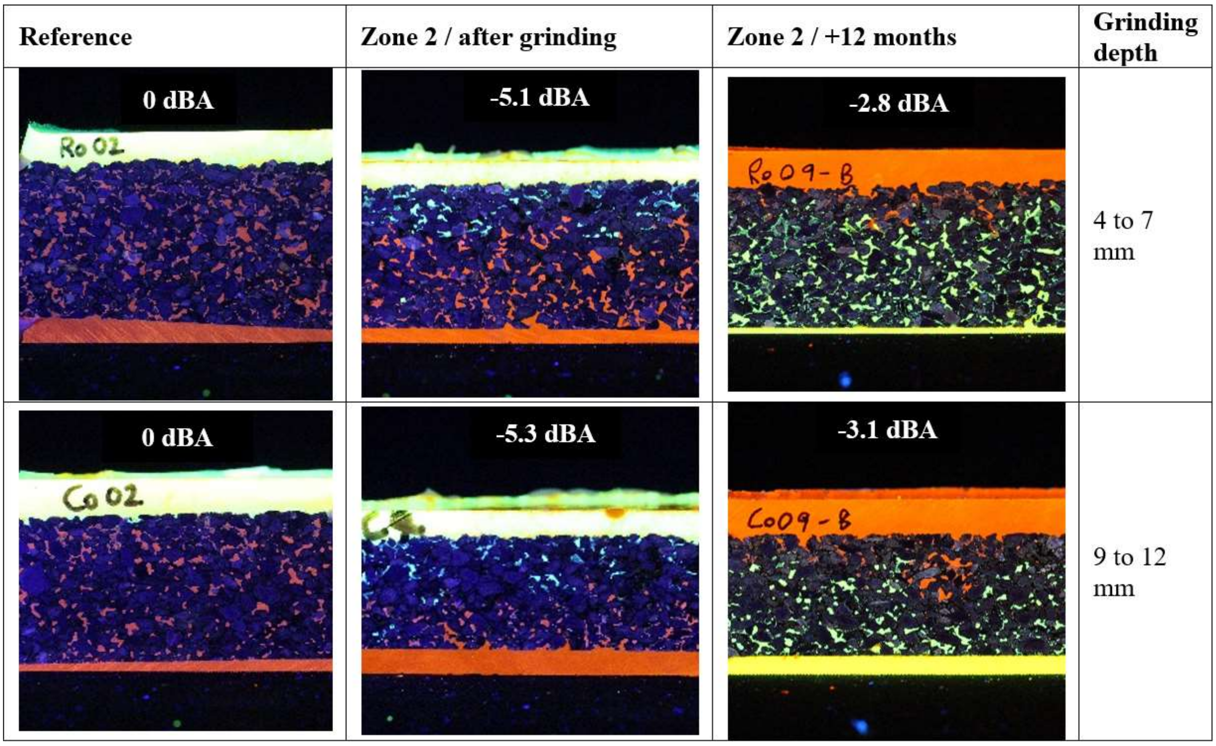


Fig. 5: Cross-sectional images representing Zone 2 in Romont (top row) and Corserey (bottom row). Acoustic performance (CPX_{car} value plotted in white) in relation to the volume of accessible pores: compared to the reference, it can be observed that grinding opened the clogged barrier layer (+ 0 month) and some of the effect seems to remain beyond one year (+ 12 months).

A similar relationship between the volume of accessible pores and the acoustic level could be observed for the large-scale maintenance sections. The pattern depicted in Figure 6 shows on the left hand side the same original conditions as in Figure 5. The pictures at the centre and the right hand side illustrate the effect of a reduced grinding depth (1 to 3 mm) six months after maintenance. At small depth the barrier layer is not removed but, with local variations, the less densely clogged pores seem to have opened at some locations, allowing the resin to partially enter the SDA layer of the corresponding core sample. This is for example the case for sample Ro13 (top right), which at the same time also shows the best acoustic performance.

There has also been experimentation that suggests the acoustic quality is not only a question of accessible porosity but also a function of the surface texture. A favourable change in surface texture most likely contributes to the acoustic gain as it has already been reported in the Swedish study for coarser porous pavements [8]. The impact of grinding on the texture of small grained (maximum aggregate size 4 mm) porous pavements (in our case SDA 4) has not yet been analysed in detail but it is a logic consequence that its contribution to the acoustic performance becomes dominant at small grinding depths. The set of images in Figure 6 indicates that the acoustic gain from the texture effect may contribute up to -2.5 dBA as it is the case for sample Co11 (bottom middle) showing hardly any accessible porosity.

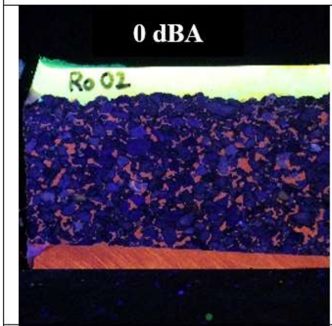
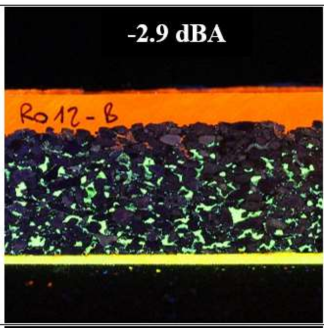
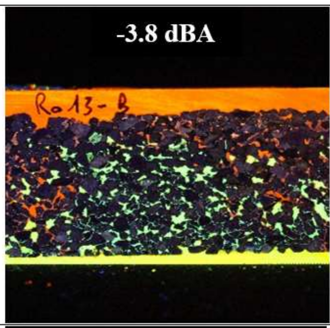
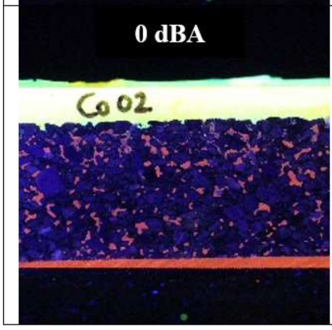
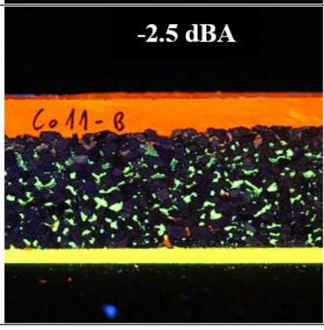
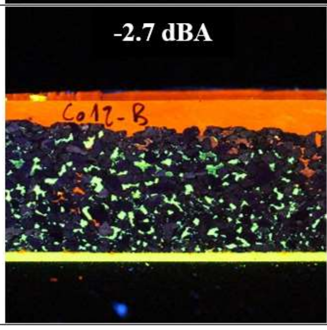
Reference	Large-scale grinding / +6 months		Grinding depth
			2 to 3 mm
			1 to 2 mm

Fig. 6: Cross-sectional images representing the large-scale grinding sections and the acoustic performance (CPX_{car} value) in relation to volume of accessible pores (top: Romont; bottom: Corserey): compared to the reference, pores seem partially accessible from the surface still 6 months after maintenance.

4. CONCLUSIONS AND NEXT STEPS

In this work, we have shown that it is feasible to maintain large sections of low-noise roads by surface grinding, regaining -3 dBA on a typical Swiss semi-dense porous pavement with small grinding depth of 1-3 mm. By using large machines arranged in a convoy of approximately 100 m in length it was possible to finish an entire road of 750 m (4500 m^2) in a single working day. Through comparisons with results from earlier pre-tests on much smaller sections but with deeper grinding (4-12 mm), it has been shown that there is a further potential in acoustic gains of up to -5 dBA. Part of the effect can be attributed to restoring access to the open-porous network that lies beneath the clogged barrier layer of an aged SDA 4 road. Reshaping the surface texture also contributes and seems to become dominant at the smallest grinding depth. An in-depth study is under way to define the interactions between grinding, changes in the mean texture depth and the improved acoustic performance. It will focus on small to moderate grinding depth but further take into account different pavement types (aggregate size and porosity). Understanding the interplay between these factors, perceiving the influence of the grinding tools, and finding the optimal grinding depth as well as cleaning process will be the topics of further studies.

Technically speaking, it is not of greatest interest to strive for high grinding depths, which will reduce the possible number of maintenance cycles during the lifetime of the pavement. First it needs to be clarified whether the extra acoustic gain from grinding off more than 4 mm will improve durability compared to the basic effect of smaller grinding depths. Gaining -3 dBA from 2-3mm grinding is already an attractive solution for the road owners that have to comply with noise regulations. SDA 4 is typically laid at a thickness of 35 mm and a sacrifice of up to 10 mm towards the end of lifetime is a realistic scenario, which would allow for 3 to 4 maintenance cycles. However, in order to provide an economically interesting solution, evidence for long-term effect over several years will be needed in the first place. The similar grinding process carried out in Sweden by Vieira et al. [8] did not show a lasting effect for more than a year. This was explained by the heavy use of studded tyres in that country, and it was assumed that in other countries the effect may remain much longer, as it was reported to in a three year study carried out in Australia [10]. Our results from the first monitoring period over 6-12 months suggest that the basis for long-term effect over 2 to 4 years is indeed given.

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