Mechanisms of acoustic aging of road surfaces

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Summary

The acoustic performance of road surfaces deteriorates with time. Texture may increase due to stone loss or, on the other hand, may decrease due to compaction and sweating of bitumen. Open surfaces may clog with dirt leading to a reduced or modified acoustic absorption and an increase of the flow resistivity. The acoustic performance of road surfaces depends on surface characteristics and any degradation is reflected in lower capacity of noise suppression. The general unpredictability of the acoustic aging and the related uncertainty in planning of maintenance and resurfacing has limited the wide spread use of these surfaces as noise mitigation measures. This study has gathered data from several countries in Europe on the age related performance of several types of road surfaces, mainly under highway conditions. This paper addresses the mechanisms causing the deterioration based on the spectral fingerprint of the wear processes.

1. Introduction

The application of low noise road surfaces has proven to be a very effective mitigation measure and has the potential to lower the level of road traffic noise up to 10 dB after laying. On several locations road traffic noise problems are solved by applying these noise reducing road surfaces. However, the acoustic performance of these road surfaces deteriorates with time. The unpredictability of this acoustic aging and the lack of knowhow on the cause and nature of the aging have limited the wide spread use of these surfaces. This study has made an inventory of existing data on initial and lifetime performance of low noise surfaces in Europe. From it we investigated the variability in aging of different types and in different areas of Europe. Studying the development of the traffic noise spectra on these surfaces give insight in the physical changes in the surfaces and thus the causes of the acoustic aging [1].

2. Description data sets

Data was gathered on the age related acoustic performance of road surfaces from several areas in Europe. Three interesting regions are defined, the Nordic area (Norway, Sweden, Finland) with harsh and long winters and the frequent usage of studded tyres. Mid-European area with moderate winter conditions and the Southern-European area with soft winter conditions.

The data preferably refers to repeated acoustic measurements at the same location over a series of years to obtain a higher accuracy of determining the aging effect. The relevant traffic data, environmental data and road construction data is appended to the measurement dataset. To be able to understand the mechanisms of acoustic aging spectral data is absolutely essential (see part 3). From 4 areas such data sets are available: Netherlands, Spain, Denmark and Norway.

The dataset consists of results of sound measurements according the Statistical Pass-by (SPB) method or the Close Proximity (CPX) method. Both methods are standardized in respectively ISO 11819-1 and ISO/DIS 11819-2.

The Netherlands data comprises a comprehensive set of data from the IPG-project. It consists of

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detailed and repeated SPB measurements for both light vehicles and heavy vehicles on several test locations on the Dutch highway system over a period of 8 to 9 years. In Figure 1 results of repeated SPB-measurements on 2-layered porous asphalt (4/8 top layer) on several locations in the Netherlands are given as a function of age of the surface.

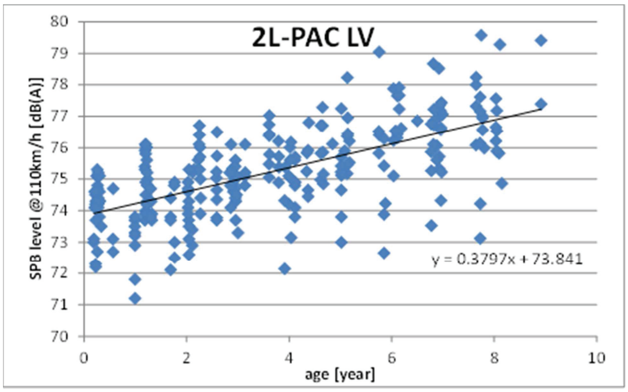


Figure 1. Example of a series of repeated SPB measurements (light vehicles) on 2L-PAC on several locations on Dutch highways. In total the data set covered nine years and are distributed over more locations.

The Dutch dataset covers three types of relevant surfaces: 1-layered porous asphalt (0/16 top layer), 2-layered porous asphalt (both with 4/8 and 2/6 top layer) and thin surface layers (0/6 top layer).

In Spain the Spanish road authority CEDEX has performed several repeated measurements on a highway and regional road in the south of Spain near Malaga. The measurements were performed with the CPX-method and covered a period of four years. Investigated road surfaces were 1-layered and 2-layered porous asphalt and a thin surface layer.

In Denmark, three studies are performed on different test sections on highways [2]. The one covering the largest time period is the study done on the M10 near Solrød. A test section with porous asphalt and one with a thin surface layer was part of the measurement program during seven years. SPB-measurements were annually performed on these test sections.

The Norwegian dataset is based on the program "Environmentally Friendly Pavements in Norway (EFR) [3]. During the project, 36 low-noise pavement test sections were constructed, mainly dense asphalt concrete surfaces with fine aggregates. In several cases also the spectral distribution is obtained.

3. Mechanisms and their spectral finger print

From past experience we learned that causes of performance loss of low noise surfaces can be traced back to specific deterioration such as clogging of the pores, roughening of the surface by stone loss or filling up of the open porous layer. These mechanisms are reflected in the spectral composition of the pass-by sound. Figure 2 illustrates the effect of changes in the surface characteristics on the spectral composition of rolling noise of car tyres. We are able to identify the following processes:

a. Effect of surface texture leads to variation in the low and mid frequent part of the spectrum. The frequencies above 1250 Hz are hardly affected. (*compare the rough dense surface with the smooth dense surface*).
b. Effect of a closed versus an open surface (actually low and high flow resistivity) is found at frequencies above 1000 Hz. In this case the lower frequencies are hardly affected. (*compare the smooth dense surface with the open surface*).
c. Creating an open layer of a certain thickness introduces acoustic absorption. (*compare the open surface with the thin absorbing*).
d. Increasing the thickness of the absorbing layer causes a shift of the absorption "dip" to lower frequencies. (*compare the thin absorbing with the thick absorbing*)

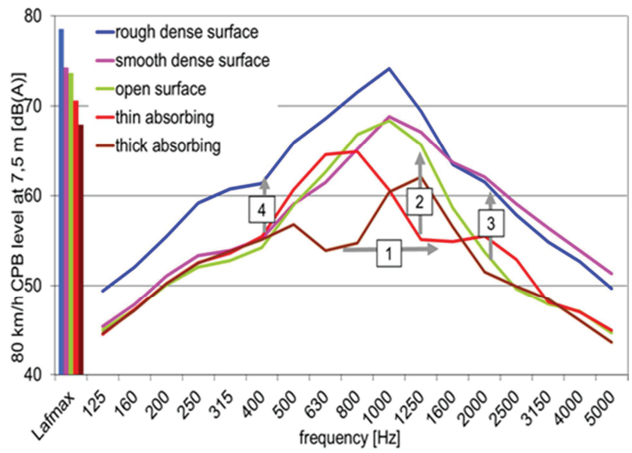


Figure 2. Spectral distribution of the different aging processes: (1) filling up of the lower layer, (2) further filling, (3) clogging of top-layer and (4) stone loss. Spectra are representative for car tyres.

4. Aging

Aging is actually reversing the mentioned processes. The numbers 1 to 4 shown in the graph (figure 2) indicate the type of change:

(1) and (2) Filling-up of the acoustic layer by dirt will cause a reduction of the thickness of the effective absorption layer and thus a shifting of the absorption "dip" to higher frequencies. Eventually nearly total clogging of the porous layer will cause loss of acoustic absorption causing an increase in the mid frequency range.

(3) Closing of the top layer by either extensive dirt or compaction of the slightly open top layer amplifies aero-acoustic noise generation and thus increases levels at the mid and high frequency range.

(4) Degradation of the surface texture through stone-loss amplifies texture induced vibration of the tyre structure, that manifests itself in the lower and mid frequency range.

The aging effects of surfaces on heavy vehicles (HV) noise are not that different from light vehicles (LV). The same trends are recognized but the effect of specific variations is different. For instance, the sensitivity to texture degradation is smaller for truck tyres than for car tyres so it may be expected that minor stone loss will not decrease reduction performance. In some occasions even an improvement is found. The effect of loss of acoustic absorption however is larger.

In this study we have investigated the spectral changes over time for a number of surface types and we have tried to interpret these changes in terms of aging mechanisms.

5. 1-layer porous asphalt (1L-PAC)

In the Netherlands a total of 7 test sections of 1L-PAC are laid, distributed over 3 locations (at two locations several sections with varying stone type and binder were laid). On these sections spectral SPB measurements are performed on a regular base (typically every year) over a period of 8 years.
All one-third-octave band data of the 7 test sections are combined into a regression diagram as a function of age and the best fitting linear function is determined. From this function the initial and 8 yr. value are calculated. The resulting graph is presented in figure 3 top for LV's and bottom for HV's.

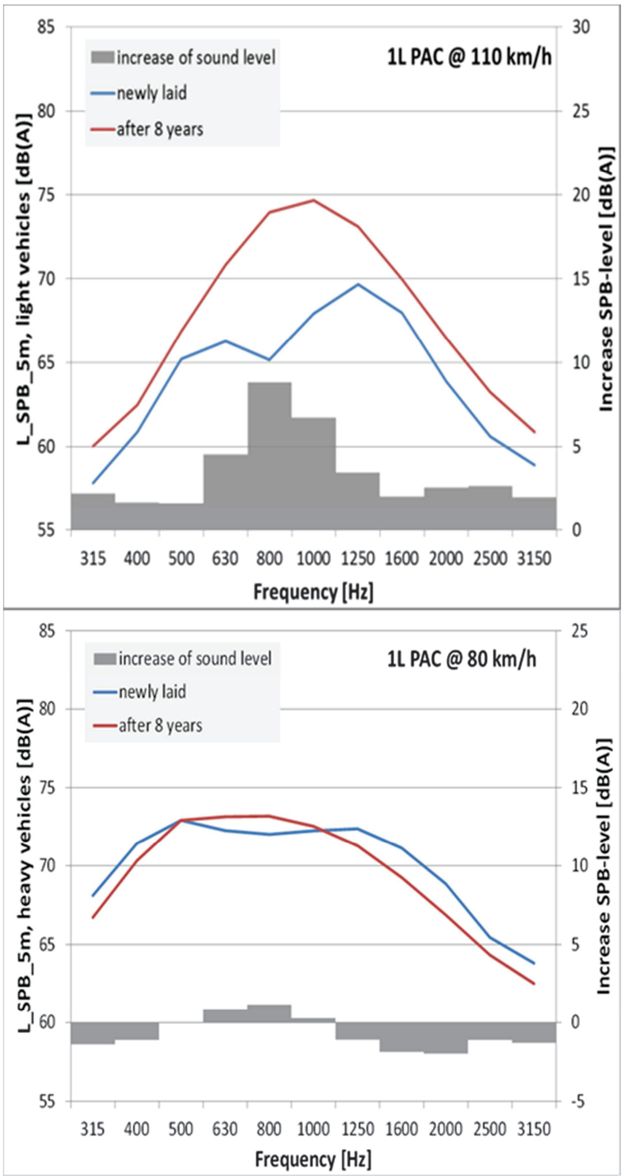


Figure 3. Spectral composition of the SPB-results for LV's at 110 km/h on a 1L-PAC 0/16 in the Netherlands. Top: the repeated measurements during a period of eight years. Bottom: initial and final spectra and their mutual spectral differences based on trend analysis. The initial and final spectrum is determined from the regression line through each 3rd-octave band. The bar graph represent the total increase in each frequency band over the period of eight years.

The spectral change of 1L-PAC for LV's follows a characteristic pattern. In the low frequency range, levels remain more or less the same and a slight increase is observed at the high frequency range. The largest change is observed in the mid

frequency range. This spectral change indicate an acoustic aging process that mainly is caused by clogging of the pores evenly over the thickness of the porous layer eventually also leading to clogging of the top. The texture remained about the same.
For HV's a different change is noticed. The increase in the mid frequency range is much smaller but surprising is the decrease low and high frequencies. No explanation can be given to this.

The results of the repeated measurements with the CPX system on the A-7 near Malaga (Spain) display a different development. Increasing sound levels at the higher frequencies (800-3150 Hz) and decreasing sound levels at the lower frequencies after four years. The increase is probably due to clogging of the top layer. No explanation can be found for the decrease at lower frequencies, other than that traffic has smoothened the texture over time.

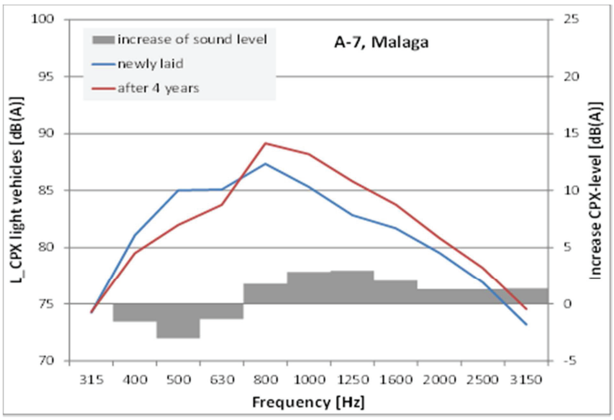


Figure 4. Spectral composition of the CPX-results for the SRTT-tyre on a 1L-PAC in Spain.

The data from the Danish tests for LV's and to a lesser extent for HV's follow the Netherlands trend but its effects are less visible in the spectra. One can notice a filling up of the indent at around 1600 Hz (see Figure 5). The increase at around 1000 Hz can also be attributed to this loss of acoustic absorption, but possibly some texture degradation is also present in the frequency range.

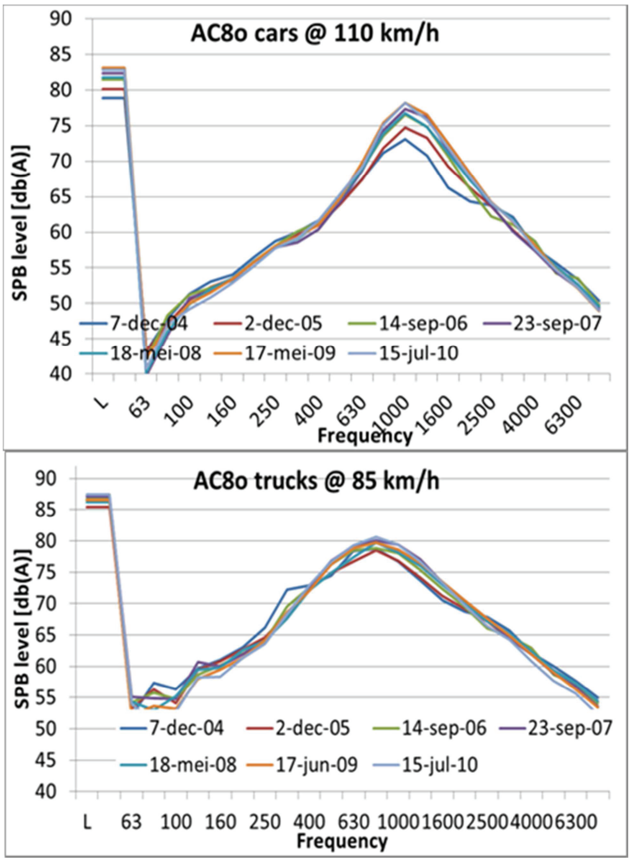
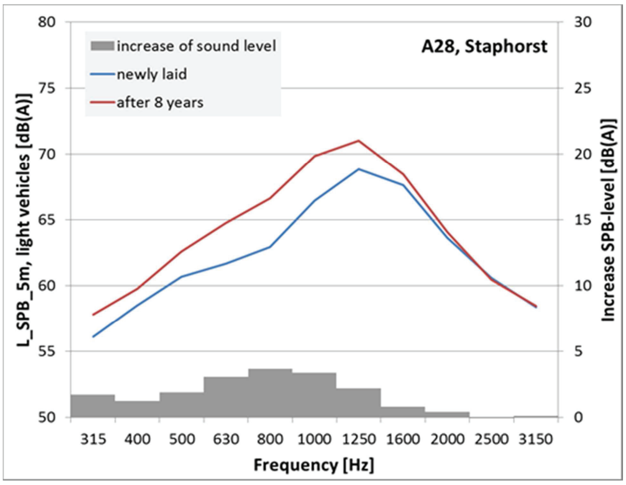


Figure 5. Results from repeated SPB measurements on the highway M10 test location wit AC8o (=1L-PAC8). Top: light vehicles, bottom: heavy vehicles.

6. 2- layer porous asphalt (2L-PAC)

The surface type 2L-PAC was of special interest in the Dutch IPG research program and sample data is available from repeated tests over a period of 8 year at several locations. On average a deterioration of 0,38 dB/yr was observed (see Figure 1) but variations between 0,15 and 0,60 dB/yr were observed. An example of an excellent performing surface and an example of a less optimal performing surface are given below (Figure 6). For the sections on the A28, near Staphorst, the deterioration is explained mild texture degradation with mild filling up of the porous layer. For the A30, near Ede, the spectral worsening can be explained by clogging of the pores, leading to both, a strong degradation of the absorption characteristics and increase of flow resistivity.

Study of the spectral trends over age show that the main effect for LV's and HV's is the filling up of the open surface, leading to loss of acoustic absorption.



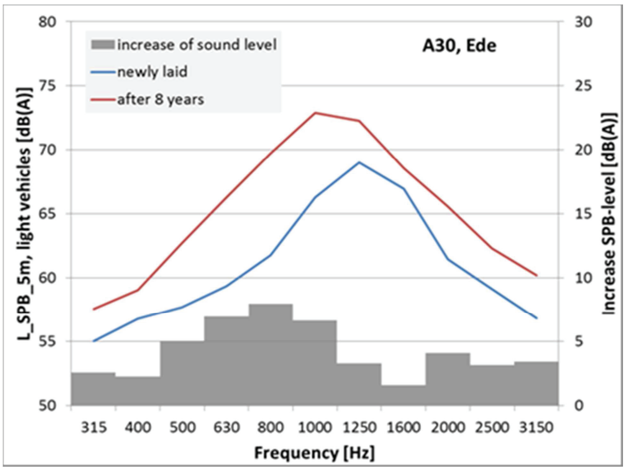


Figure 6. Examples of spectral distribution of aging of 2L-PAC on two locations. Top A28 near the village of Staphorst, bottom the A30 near Ede. Each graph displays the initial spectrum and the spectrum after eight years, based on regression analysis. The bar graph represent the increase in each frequency band after eight years. Each graph displays the average over six test sections on each location.

7. Thin surface layers (TSL)

The typical acoustic degradation of thin surface layers is shown by the examples in Figure 7, the A58 near Oirschot (NL) and Figure 8, the M10 near Solrød(DK). Thin surface layers are not high absorptive road surfaces such as 1L-PAC and 2L-PAC. For thin surface layers the increase of flow resistance is the main cause of degradation. It is caused by either extensive dirt or compaction of the slightly open top layer. This process lead to an increase of sound levels at the mid and high frequency range (1000-3150 Hz).

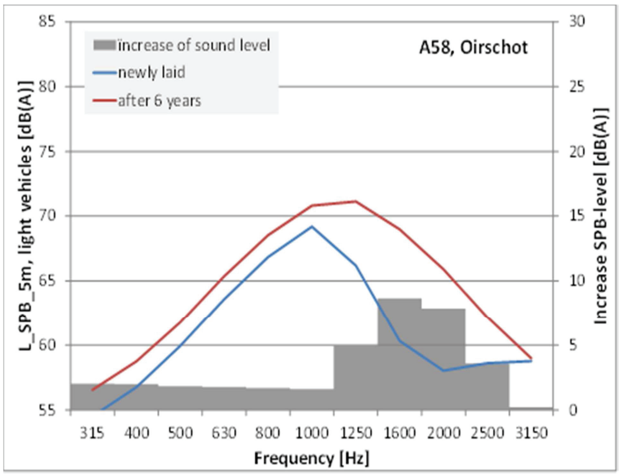


Figure 7. Spectral distribution of aging of a thin surface layer (A58, Oirschot, Netherlands). Each graph displays the initial spectrum and the spectrum after six years, based on regression analysis. The bar graph represent the increase in each frequency band after six years.

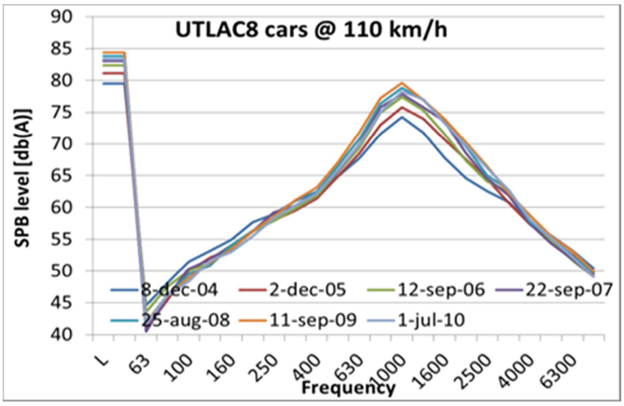


Figure 8. Spectral distribution of aging of a thin surface layer (M10, Solrød, Denmark).This graph shows the results of SPB-measurements over a period of seven years.

8. Dense surfaces

The winter conditions in Scandinavian countries are severe. Low noise surfaces such as TSL and PAC are too vulnerable and the focus is on dense asphalt surfaces with a small maximum aggregate size (0/6 and 0/8). On the Highway E16 several test sections with dense asphalt concrete (DAC) with variable aggregate sizes are constructed and annually measured by the CPX-method. A dense surface has no acoustic absorption. The only acoustic aging effect that will be found is the degradation of the texture. In Figure 9 the aging of the DAC 0/6 test section is shown.

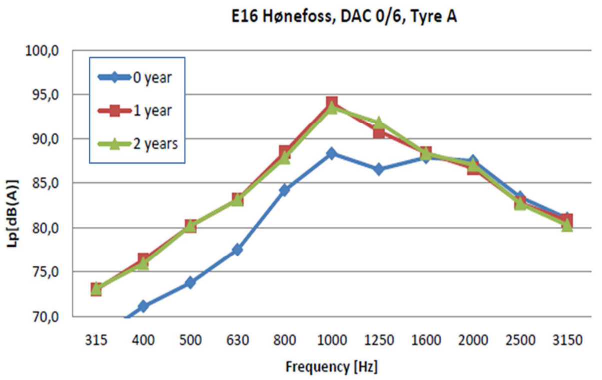


Figure 9. Spectral distribution of aging of a dense asphalt concrete 0/6 (E16, Hønefoss, Norway). This graph shows the results of CPX-measurements repeated after one and two years [4].

Right after the construction, before the first winter season, amplitudes below 1600 Hz are considerably lower than in the later stage. After the first winter season, the increase of the sound levels is likely related to the roughening of the surfaces. In the Nordic countries the service life of road surfaces is much shorter than on the European mainland. This is caused by a wide use of studded tyres during the winter in the Nordic countries.

9. Conclusions

This study has collected repeated noise measurements from several areas in Europe and from a range of surfaces and surface types. A wide variation of age effects has observed between different surface types, ranging from almost no effect up to 5 dB/yr.

The processes causing the loss of acoustic performance are identified by means of the spectral changes that are recorded during service life. For thin surface layers, clogging of the pores is the main cause. For porous surfaces the performance loss can be explained by loss of acoustical absorption on one side and mild texture degradation on the other.

The wear by studded tyres in Scandinavian countries constitute a specific cause, leading to a quick deterioration of the surface texture, noted by the strong increase in the low and medium spectral range over time.

Understanding the causes of acoustic deterioration can help to improve the average service life of low noise surfaces and to decease the variation between comparable situations. It was found that for some surface types the intensity of HV's helps to explain variation. However the best performing surface in Figure 6 also had the highest HV intensity. Other factors, still unknown, are to be taken into account.

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