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Test sections to study the acoustical quality and durability of thin noise reducing asphalt layers

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ABSTRACT

Within the context of the European Noise Directive, action plans have been established. Noise reducing road surfaces are seen as a cost-efficient measure for traffic noise abatement. Therefore ten test sections were installed in May 2012 in Belgium, with the objective of integrating noise friendly bituminous wearing courses in the Flemish road surface policy in a later stage. Eight test sections are paved with hot laid, bituminous wearing courses with a thickness of maximum 30 mm and a maximum content of accessible voids of 18 %. The other two sections consist of a double layer porous asphalt (PA) and a stone mastic asphalt (SMA) (reference section). The acoustical quality assessed during measurement campaigns in the first two years after construction is discussed in this paper. Statistical Pass-By (SPB) and Close-ProXimity (CPX) measurements are performed according to ISO 11819 within certain time intervals to follow up the evolution. Also other important factors, like durability, are studied. Resistance to raveling and adhesion to the base course are critical parameters for the lifetime of a thin noise reducing asphalt layer because of the high void content and limited thickness. BRRC measured the raveling resistance on test plates made with the asphalt mixtures sampled at the construction site. Tensile adhesion and shear bond tests were performed on drilled cores to measure the adhesion of the wearing course to the base course. Results of these laboratory raveling and adhesion tests are linked to the evolution on site and to the evolution of the noise measurement results.

Keywords: Thin asphalt layer, Road surface, Durability I-INCE Classification of Subjects Number(s): 51.4

1. INTRODUCTION

The Flemish Agency for Roads and Traffic planned the construction and follow-up of test sections consisting of thin noise reducing asphalt layers in 2012, mainly to study the acoustical quality, but also other characteristics like durability and skid resistance. Measurements are performed in cooperation with the Belgian Road Research Centre (BRRC). A student of the University of Antwerp made some noise measurements as well in the framework of her master’s thesis (1).

Through a call for tender eight different variants of thin surface layers were selected. As an evaluation, besides the regular performances, like skid resistance and evenness of the surface, also acoustical performances are studied.

A suitable location was found on the regional road N19 Turnhout-Kasterlee in Belgium, which is a road with two lanes in each direction. On average about 9340 vehicles pass the test location daily during working days, of which 16 % are heavy vehicles. On average during the weekend about 7140 vehicles pass daily of which 5 % are heavy vehicles[4]. A stretch of 2 km long was divided into ten sections of each 200 m length. Two sections were used for the reference surfaces: stone mastic asphalt with a maximum aggregate size of 10 mm (SMA-10 on test section 1) and double layer porous asphalt (2-layer PA on test section 5). The eight remaining sections were paved with thin asphalt layers.

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Sections 8 and 9 were paved with the same bituminous mixture at a different thickness (25 and 30 mm).

Besides checking the acoustical performance the mechanical performance of the sections is also evaluated. Durability is an important issue, not only for the lifetime of the pavement, but also for the evolution of the acoustical quality over time since raveled sections, delaminated zones and potholes are detrimental. Knowing that asphalt mixtures for thin asphalt layers are generally more sensitive to raveling and delamination than conventional asphalt mixtures, the focus in this paper for the mechanical performance is on raveling and adhesion tests. No tests of mechanical performance were performed on 2-layer PA as it was constructed as an extra reference for the acoustical quality only.

Chapter two deals with the construction of the test sections, followed by a short description of all test methods that were used in this study in chapter three. Next the acoustical quality is investigated in detail in chapter four, texture results are discussed in chapter five, raveling resistance is studied in chapter six and interlayer bonding is explored in chapter seven. Chapter eight deals with the visual inspections of the test sections. In chapter nine the relationship between acoustical quality and durability is investigated further. Finally some conclusions are made.

2. CONSTRUCTION OF THE TEST SECTIONS

The performance characteristics of thin layers are known to be very sensitive to the paving conditions. Adverse weather conditions, inadequate compaction temperatures or poor quality of the tack coat are some of the parameters that may seriously affect the performance of the pavement. To make a correct evaluation of the different types of surface layers, it is essential to monitor the construction and to measure the critical parameters during and after construction. The performed infrared measurements showed large variations in temperatures due to the fast cooling of the thin layers. However, the final density of the thin wearing courses, as measured with a nuclear densitometer, is sufficiently uniform within each section. This is due to the fact that the compactors followed the asphalt finisher very closely and compacted the wearing course in an efficient way.

During the paving of sections 2 and 3 it was raining. After the installation of section 3 the paving was interrupted due to the heavy rainfall. Although water pools were removed before continuing with the paving of section 4, there was still some remaining moisture on the surface. This remaining moisture and the faster cooling of the asphalt during the construction of sections 2 and 3 in the rain are not ideal working conditions. There were also some problems during the spraying of the tack coat: some of the nozzles were clogged and therefore the tack coat locally showed an inhomogeneous aspect. This can lead to a local debonding of the wearing course.

3. TEST METHODS

In this chapter the different measurement methods and the corresponding equipment are described.

3.1 Acoustical quality

3.1.1 SPB

Standard ISO 11819-1 (2) describes the SPB or “Statistical Pass By” method. Following the standard the speed and the maximum sound pressure level of minimum 100 cars and 80 heavy vehicles are measured. The measurement is performed during their passage in front of a microphone which is installed next to the road surface of which the acoustical quality has to be assessed. A graph with the maximum sound pressure level in function of the logarithm of the vehicle speed is plotted and the average value of the maximum sound pressure level is calculated at a reference speed (L_{veh}). In this study the reference speed is 80 km/h and no heavy vehicles are taken into account as too little heavy traffic passes at the test location. SPB measurements are performed using both the measuring equipment of BRRC and of the Flemish Agency for Roads and Traffic.

3.1.2 SPB

Standard ISO 11819-2 (3) describes the CPX or “Close-Proximity” method. Tyre/pavement noise is measured by driving over the road surface with a trailer. The CPX method differs from the SPB method as it only takes into account the tyre/pavement noise and no other vehicle noise sources. In contrary to the SPB method it does not comprise propagation effects as the measurements are performed very close to the tyre. The main purpose of the CPX-method is to evaluate the noise production and homogeneity of the road surface over a certain distance. The CPX trailer of the Flemish Agency for Roads and Traffic is used in this study. Two times two microphones are mounted close to the tyre/road contact in two acoustic isolated chambers which are attached to the trailer. Measurements are performed at reference speed 80 km/h with two different reference tyres, namely Standard Reference Test Tyre (P1) and Avon AV4 (H1), representative for car and truck tyres respectively. As a result the noise levels of 20 m road sections and the noise level of the total test section (L_{cpx}) are obtained.

3.2 Texture

Texture is measured with the dynamical laser profilometer of BRRC following standard ISO 13473 (4)-(6). The laser combines a high sampling frequency (78 kHz) with a small diameter of laser beam (0.2 mm). The laser profilometer has a vertical measuring range of 64 mm and consists of a 16-bit system. The vertical resolution is 1 µm. Tests for this study were performed at a low speed in the right wheel track with a step size of 0.2 mm.

3.3 Raveling resistance

The equipment used at BRRC is the Darmstadt Scuffing Device (DSD). It is one of the four types of equipment described in the present version of a new technical specification which is being developed by Technical committee CEN/TC227/WG1 “Bituminous mixtures” (7).

In this test, a tyre is lowered with a controlled force onto the surface of a test plate (260 mm by 260 mm) while the plate performs a combination of translations and rotations. This simulates the mechanical effect of vehicles on the wearing course when they are accelerating, braking or turning. The loss of material measured in the test is a direct measure of the resistance to raveling.

Tests for this study were made at room temperature, with a tyre pressure of 300 kPa and a vertical load of 1000 N. The test plates were compacted at BRRC with a plate compactor according to EN 12697-33 (8). The bulk mixtures were sampled directly from the finisher at the time of paving.

3.4 Interlayer bonding

Technical committee CEN/TC227/WG1 “Bituminous mixtures” recently proposed a prestandard prEN 12697-48 (9) in which three different interlayer bonding tests are considered (Torque and shear bond tests and a tensile adhesion test). In this study two interlayer bonding tests are used: the shear bond test (SBT) and a tensile adhesion test (TAT) developed at BRRC (10) before the appearance of prEN 12697-48.

The types of equipment and the procedures used in this study are described in 3.4.1 and 3.4.2.

3.4.1 Tensile bond strength

BRRC working method MM – MPT – 02.02 (10) describes the tensile adhesion test. Metal plates are glued to both sides of the specimens (80 mm by 80 mm). These are conditioned and tested at 10 °C (± 1 °C).

A tensile load is applied in strain-controlled mode (0.5 mm/min) until the specimen fails. Tensile bond strength is calculated as the average of five specimens.

3.4.2 Shear bond strength

Prestandard prEN 12697-48 (9) describes the shear bond test (SBT). At BRRC, the specimens are cores with a diameter of (150 ± 2) mm. In case of thin or very thin surface layers, a metal extension plate is glued to the surface course, to avoid deformation of the surface layer and distribute the shear load correctly over the interface.

The specimens are conditioned and tested at 20 °C, using a Leutner shear test device with a 5-mm gap between the shearing rings. The test is strain-controlled at a rate of (50 ± 2) mm/min.

Repeatability tests at BRRC (11) have shown that, in case of surface layers with a thickness less than 30 mm, six specimens need to be tested to calculate the arithmetic average shear bond strength.

4. ACOUSTICAL QUALITY

4.1 SPB

SPB measurement campaigns are performed within several time intervals: 1, 11, 15 and 22 months after construction. The first five test sections (1 – 5) are measured by BRRC and the last five test sections (6 – 10) are measured by the Flemish Agency for Roads and Traffic.

Unfortunately due to some problems with the measurement equipment, not all test sections were monitored at every measurement campaign. Only the results of the complete measurement campaigns are shown in Figure 1. The results represent one measurement point per test section. The 95 % confidence intervals are shown as error bars. Test sections 1 (SMA-10) and 5 (2-layer PA) are the reference test sections. It was requested to keep the other numbered test sections anonymous. All of them are thin noise reducing layers. All results have been corrected for temperature using a temperature correction coefficient of -0.06 dB(A)/°C and a reference temperature of 20 °C (12).

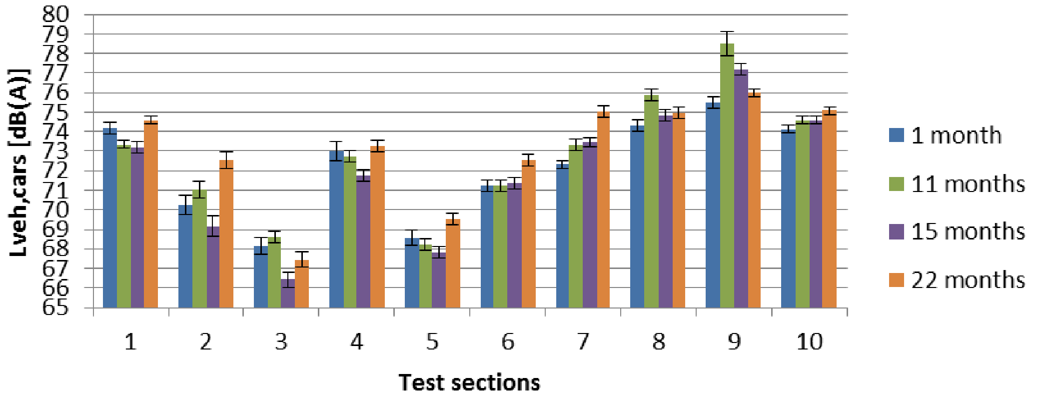

Figure 1 – Overview of SPB measurements (Lveh, cars) performed 1, 11, 15 and 22 months after construction (with temperature correction) with 95 % confidence intervals. Reference speed is 80 km/h.

The initial acoustical quality of reference test section 1 is surprisingly good for an SMA-10. A typical SMA-10 is expected to be noisier.

All test sections become more noisy over time, except for test section 3. Test sections 2 and 7 show the largest increase of L_{veh} over a period of 22 months, 2.3 and 2.7 dB(A) respectively. Test section 3 shows a tendency for an increased noise reduction. Although at the beginning a decrease of L_{veh} is noted for reference test section 1, over a period of 22 months an increase of 0.4 dB(A) is noted. Test sections 4, 8, 9 and 10 are the most stable in time with a maximum increase of L_{veh} of 1 dB(A).

Assuming a linear relationship between time and L_{veh} the ageing effect is assessed. Reference test sections 1 and 5 have an increase of 0.03 and 0.04 dB(A) per month respectively. Thin layers increase with 0.03 to 0.16 dB(A) per month, except for thin layers 3 and 4. Thin layer 3 seems to decrease with 0.03 dB(A) per month while thin layer 4 remains rather stable over time. This decrease of test section 3 is not in line with the CPX measurement results (as shown in the following paragraph).

4.2 CPX

CPX measurement campaigns are performed within several time intervals: 1, 5, 11, 15, 18, 22 months after construction. All results have been corrected for temperature using a temperature correction coefficient of -0.03 dB(A)/°C and a reference temperature of 20 °C (3).

4.2.1 Cars

The results of the measurements performed at 80 km/h with the P1 tyre are shown in Figure 2.

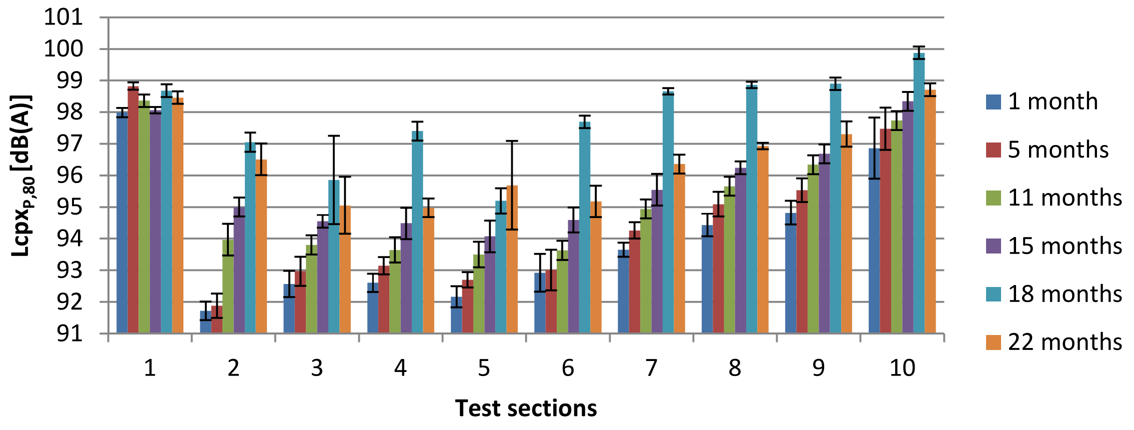

Figure 2 – Overview of CPX measurements performed 1, 5, 11, 15, 18 and 22 months after construction with the P1 tyre at 80 km/h (with temperature correction). Standard deviations based on 20 m segments.

18 months after construction all thin layers show a sudden noise increase. The cause for these high sound pressure levels remains unclear to this date. The measurements are performed on a cold day in November. The air temperature was 11 °C but the surface temperature was near freezing temperature. Perhaps some remains of salting influenced the measurements. SPB measurements performed on test sections 6, 7 and 8 on exactly the same date (not shown in previous chapter because the campaign was incomplete) confirm these higher sound pressure levels that are found with CPX method. However ISO 11819-1 demands a minimum surface temperature of 5 °C, a requirement which was not met for this campaign. The authors plan new measurements on a cold day to confirm this possible cause.

The acoustical quality of the reference test section SMA-10 remains more or less stable over time. All the other test sections show an increase of sound pressure levels. While L_{veh} of test section 3 is lower after 22 months compared to the beginning (see par. 4.1), L_{cpx} is higher. This may be explained by the fact that the measurement point for SPB is situated in a part which shows less raveling.

Test sections 3 and 5 reveal a high inhomogeneity after 18 and 22 months (shown as a large standard deviation). The visual inspections indeed show several zones of raveling which change the surface texture and therefore the acoustic quality within these sections. The acoustical quality of test section 10 is not homogeneous in the beginning but the homogeneity has improved over time.

Figure 3 shows the sound pressure level reductions with respect to reference test section 1 at different moments in time. The sound pressure level reductions decrease over time for all test sections. Test section 10 even reveals a sound pressure level which is higher than the reference after more than one year.

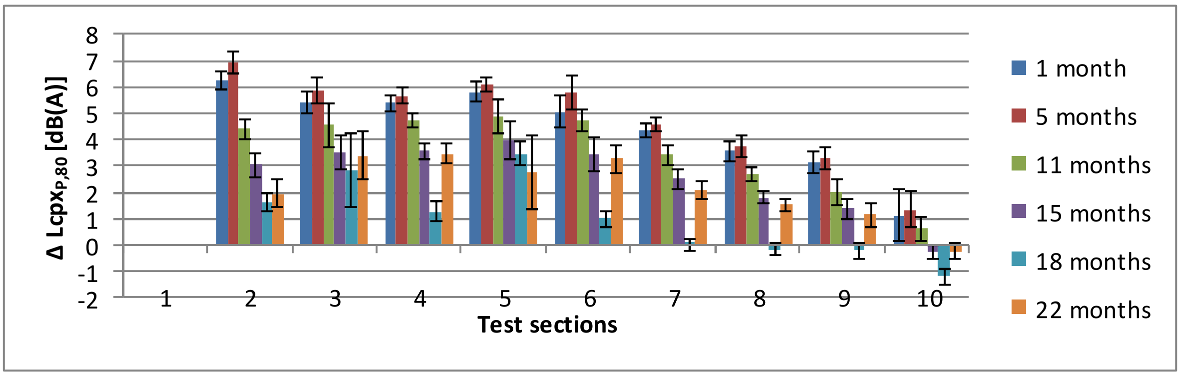

Figure 3 – CPX sound pressure level reduction (with temperature correction) of all test sections compared to reference test section 1 (SMA-10) with the same age (measured with P1).

While in the beginning noise reductions of 1 to 7 dB(A) were observed, after almost two years noise reductions of only 0 to max. 3.5 dB(A) remain. Double layer porous asphalt (test section 5) showed an initial noise reduction of 5.8 dB(A), while after two years only 2.8 dB(A) remains.

The evolution in time of the acoustical quality measured with P1 is assessed, assuming a linear relationship. L_{cpx} of reference test sections 1 and 5 shows an increase of 0.01 and 0.18 dB(A) per month respectively. L_{cpx} of thin layers has increased between 0.12 and 0.28 dB(A) per month, which is more than expected. Danish research on test sections with thin layers (13) revealed an average annual noise increase of 0.05 to 0.06 dB(A) per month, which is much lower than the loss of noise reduction that was found in this paper.

4.2.2 Heavy vehicles

The results of the measurements done at 80 km/h with the H1 tyre are shown in Figure 4.

18 months after construction all test sections show a sudden noise increase. The same effect, yet even more apparent, was discussed for the measurements with the P1 tyre (see par. 4.2.1).

The sound pressure level of reference SMA-10 is increasing over time, while it was stable for the measurements with the P1 tyre. All test sections show an increase of sound pressure levels over time.

Test sections 5 and 7 reveal the largest inhomogeneity after 22 months. The large inhomogeneity that was observed for test section 3 in 4.2.1 is not observed here. Possibly the truck tyre is less sensitive to texture change due to raveling than the car tyre. The homogeneity of the acoustical quality of test section 10 has improved over time. This is similar to the measurements with the P1 tyre.

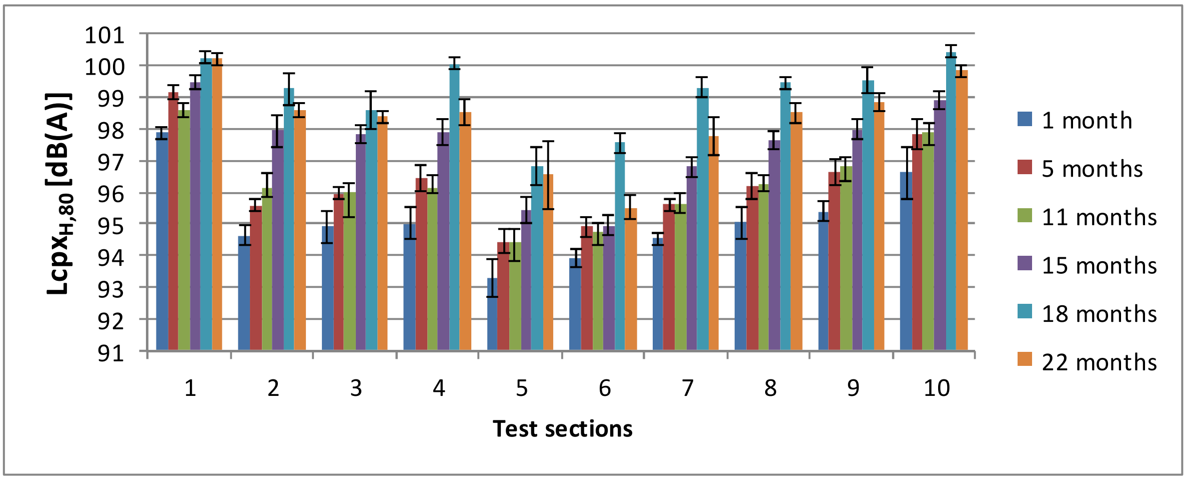

Figure 4 – Overview of CPX measurements performed 1, 5, 11, 15, 18 and 22 months after construction with the H1 tyre at 80 km/h (with temperature correction). Standard deviations based on 20 m segments.

Figure 5 shows the sound pressure level reductions with respect to reference test section 1 at different moments in time. The sound pressure level reductions decrease over time for all test sections, except test section 6 where a small increase is observed.

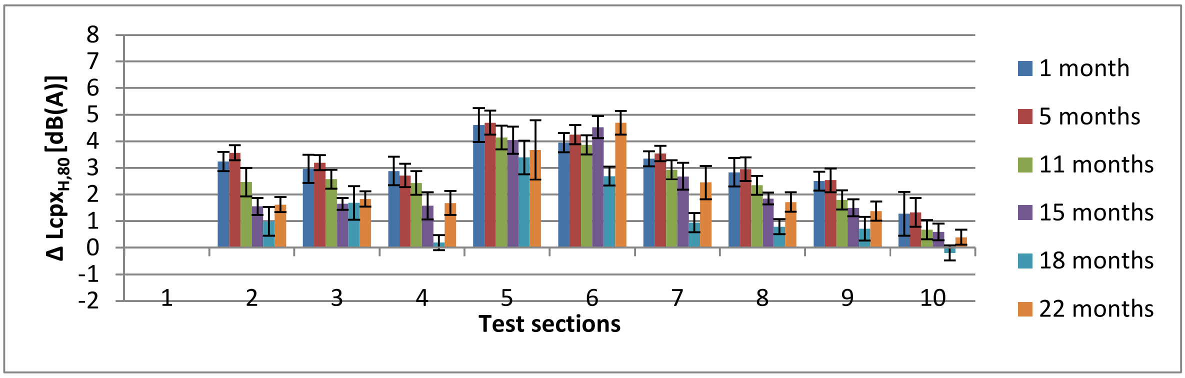

Figure 5 – CPX sound pressure level reduction (with temperature correction) of all test sections compared to reference test section 1 (SMA-10) with the same age (measured with H1).

The evolution in time of the acoustical quality measured with H1 is assessed, assuming a linear relationship. Reference test sections 1 and 5 show an increase of 0.11 and 0.17 dB(A) per month respectively. Thin layers show an increase between 0.11 and 0.23 dB(A) per month. For all thin layers, except test section 2 and 6, the ageing effect for cars is smaller than for heavy vehicles. However the difference is more significant for those two sections for which the ageing effect is smaller for heavy vehicles than for cars. In recent Danish research the ageing effect was found to be smaller for heavy vehicles than for cars on a larger range of various surfaces (14).

5. TEXTURE

Texture measurements were performed 2, 5, 10 and 24 months after construction. Two test sections reveal a significant texture change, namely thin layer 2 and double layer porous asphalt 5, which are shown in Figure 6.

Texture is stable in the first five months (during summer period) while a clear increase is visible 10 months after construction (after winter period). Two years after construction again an increase of texture can be seen. The increase covers the complete megatexture range and a part of the macrotexture range. An increase of megatexture may result in more tyre vibrations and thereby noise.

A part of the increase of CPX noise pressure levels after 10 months may be due to the increase in megatexture (see Figure 2 and Figure 4). As no measurements of absorption and mechanical impedance were performed it is difficult to state this with certainty.

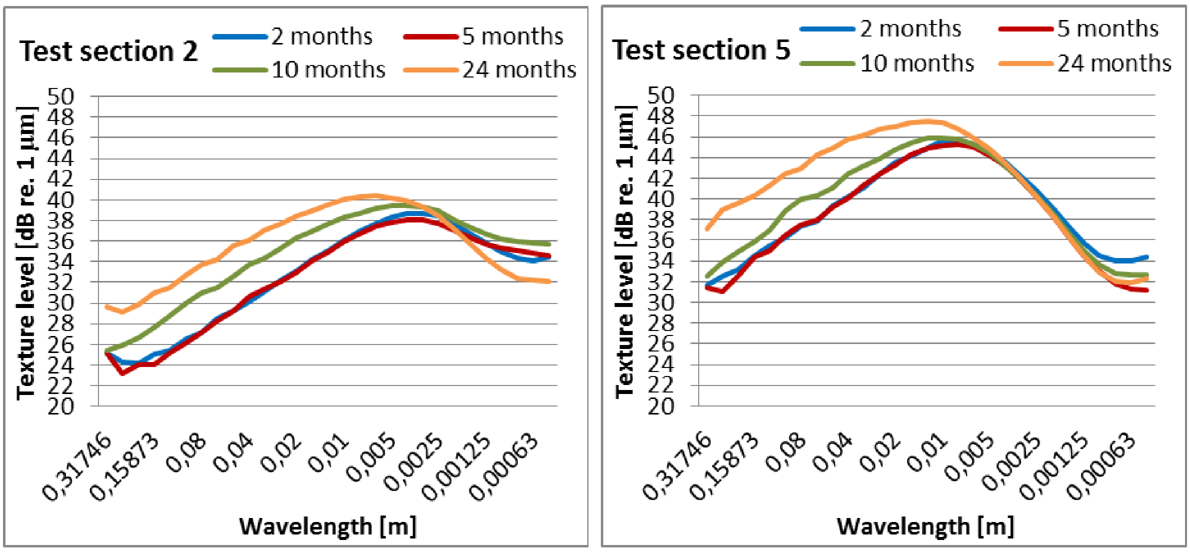

Figure 6 – Texture spectra of test section 2 (left) and 2-layer PA (right) measured 2, 5, 10 and 24 months after construction.

6. RAVELING RESISTANCE

Samples were taken from the asphalt mixtures at the construction site during paving. These were reheated and compacted in the laboratory to make test plates for the raveling tests. Two plates were tested per variant. The average results of the raveling tests are shown in Figure 7 for the SMA-10 (section 1) and for the mixtures for thin layers. The right graph is the same as the left graph but with different scale to make the difference between sections more clear. Only the double layer PA (section 5) was not tested in the laboratory. Sections 8 and 9 are paved with the same mixture, but with a different thickness. The tests make a clear distinction between sections 2 and 3 with a lot of material loss and all the other sections with only moderate or little material loss. Sections 7, 8 and 9 even present a very good resistance to raveling equivalent to SMA.

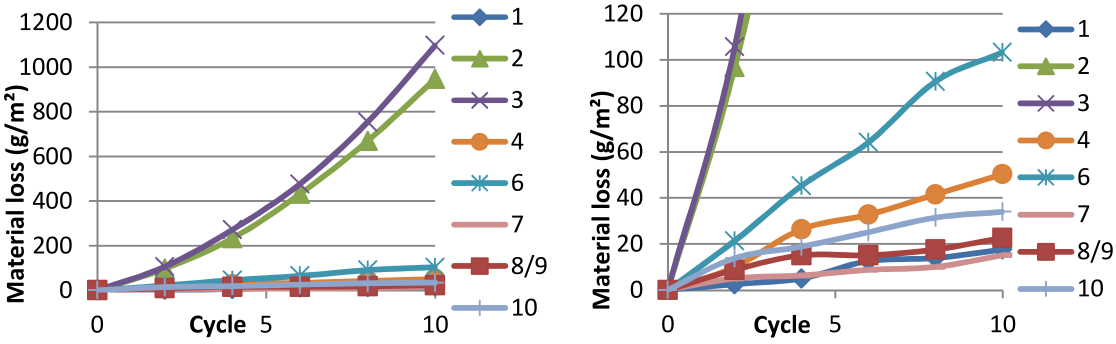

Figure 7 – Material loss in the raveling tester (both graphs are the same with different scales).

7. INTERLAYER BONDING

In order to obtain representative results, cores were taken in different areas of each test section, except reference section 5 and thin layer 8. Thin layers 8 and 9 are paved with the same mixture, but with a different thickness. Both shear and tensile strength were determined on different cores (see par. 3.4), since previous research has shown that the tests are complementary. Figure 8 shows the results.

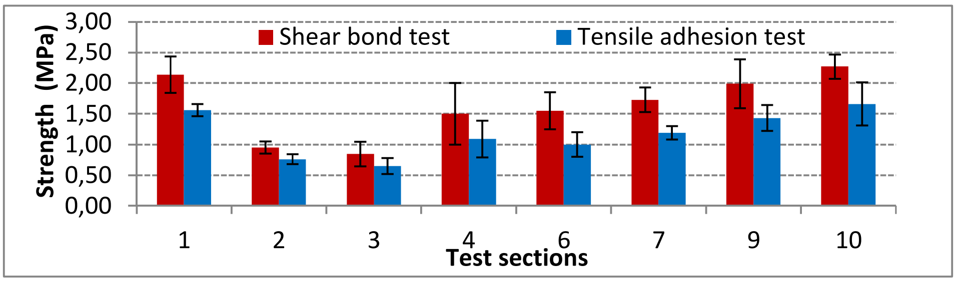

Figure 8 – Results for shear and tensile strength as determined on cores from test sections.

Figure 8 leads to the following general conclusions:

- Minimal required shear strength in German and Swiss specifications is 0.85 MPa (15, 16) and this requirement is met for all sections, albeit barely for section 3. With the exception of sections 2 and 3, all sections satisfy even the stronger requirement of 1.42 MPa as specified in a German study (17).
- For all test sections, except sections 2 and 3, a tensile strength of 1.0 MPa was obtained. As currently no specification exists in which a requirement for tensile strength of thin layers is defined, the latter was chosen based on similar tests described in prEN 12697-48 (9). The direct tensile test is complementary with the shear test. Indeed, in the direct tensile test the interface as well as the wearing course and the base course itself are exposed to tensile stresses. The following information was obtained by observing the failure zone:
  - for the reference section and the sections 9 and 10, failure did not occur in the tack coat, but in the wearing course (section 1) or the base course (sections 9 and 10). Higher tensile strength values were obtained for those test sections, suggesting a higher strength of the tack coat itself;
  - for the other test sections, mixed failure occurred (in tack coat and wearing course).
- Typical for these test sections was the broad scattering of test results with coefficients of variation of 10 % to 31 % for the shear test and of 7 % to 27 % for the direct tensile test. Previous in situ shear tests on SMA showed that a coefficient of variation of less than 10 % is achievable (16). Probably, results were influenced by the conditions during construction. Numerous factors such as rain showers, an uneven or a locally damaged tack coat, large temperature variations, etc. may contribute to a broad scattering of results (see chapter 2).

A more detailed analysis linking the construction of the test sections (see chapter 2) to test results led to the following conclusions:

- Bonding between layers is largely influenced by the composition of the wearing course. This explains the large difference between test sections 2 and 3 on the one hand and test section 7 on the other hand, notwithstanding the fact that a similar tack coat was applied. Rain during construction of test section 3 had most likely a negative influence as well.
- The tack coat definitely has a decisive influence on bonding between layers as was found when comparing sections 7 and 9. Test sections 7 and 9 have a wearing course with a similar grading, void content and binder, but the tack coat differs (for sections 7 and 9 respectively an unmodified tack coat and a polymer-modified tack coat ere applied). Moreover, the bitumen emulsion was better applied on test section 9. This is confirmed by the higher values for bonding between layers for test section 9.

8. MONITORING OF THE TEST SECTIONS

Visual inspections are made once or twice a year to register the locations and measure the severity of possible damage. The purpose of these inspections is firstly to study the durability of the thin layer sections and to validate the durability tests described in the previous sections and secondly to assist in the interpretation of the evolution of the acoustic quality of the wearing courses.

The distinction in raveling resistance made by the laboratory tests is confirmed by the visual inspections after less than two years. Sections 2 and 3 already show raveling locally, especially in the wheel tracks (see Figure 9). In section 3 a pothole with a diameter of 10 cm was also observed. Severe raveling was detected on section 5, especially at the beginning and end of this section (see Figure 10).

Figure 9 – A picture of the raveling seen in test section 2.

Figure 10 – A picture of the severe raveling at the end of test section 5 (left) and a CPX measurement with P1 on this test section one month earlier (right).

During inspections contamination with dirt of the test sections was observed coming from fields nearby. Often agricultural machinery was passing at the location. This may have influenced the sound absorption negatively and therefore the accelerated loss of noise reduction in time.

9. RELATIONSHIP BETWEEN ACOUSTICAL QUALITY AND DURABILITY

CPX measurements with the P1 tyre reveal a sudden increase of sound pressure level between 5 and 11 months after construction for test section 2 (see Figure 2). CPX measurements with the H1 tyre reveal a sudden increase of sound pressure level between 11 and 15 months after construction (see Figure 4) for test sections 2 and 3. In laboratory test sections 2 and 3 were found to have the least raveling resistance (see chapter 6). Raveling is also visible in a texture change (see Figure 6) for test section 2 which occurs later than 5 and 10 months after construction. Visual inspections link the results of the CPX measurements and the texture change to raveling which occurred in that period.

The average CPX sound pressure levels over short measuring distances (segments of 20 m each) were determined to detect large differences per test section. Mostly inhomogeneity over the various 20 m road segments could be linked to the visual inspections which showed raveling damage. Deviating noisy 20 m road segments were often due to local raveling. An example is given in Figure 10 for test section 5.

Results of shear and tensile strength were found to be significantly lower for test sections 2 and 3 (see Figure 8), but until now no significant degradations were observed on site which may be linked to these laboratory results. However, the thin layers are only two years old at the time of writing this paper. More time is probably needed to link these laboratory results to degradations on site.

10. CONCLUSIONS

Assuming a linear relationship the ageing effect on noise reduction is assessed. Thin layers show a noise increase of 0.11 to 0.28 dB(A) per month based on CPX measurements. The ageing effect is smaller for SPB measurements with 0.03 to 0.16 dB(A) per month. All these results are larger than expected.

Shortly after construction, on all test sections except test section 10, more noise reduction is obtained for car tyres than for truck tyres. This changes over time as some thin layers reveal more noise reduction for truck tyres than for car tyres after almost two years.

For all thin layers, except two sections, the ageing effect for cars is smaller than for heavy vehicles. However the difference is more significant for those two sections for which the ageing effect is smaller for heavy vehicles than for cars.

Noise increase is clearly linked with raveling. The high sensitivity to raveling can easily be explained by the composition of the mixtures (aggregate grading and bitumen content) and the high void content.

The results indicate that it is difficult to realize an excellent noise reduction and durability at the same time. The best compromise between these goals should be sought. A well thought choice should be made based on the characteristics of the construction site. Thin layers are not applicable at places like urban road crossings or others where vehicles exert high shear forces on the surface layer. Extra care should be taken during construction as thin layers have a higher sensitivity to weather conditions during paving.

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