



INVESTIGATION INTO A LONG-TERM INTERLAYER BONDING OF ASPHALT PAVEMENTS

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Abstract. In recent years adhesion testing of pavement layers has gained more and more importance throughout Europe. In a lot of projects the bonding properties are determined after construction and many countries have developed standard requirements which the obtained bonding values have to fulfil.

The paper focuses on the question of long-term behaviour of bonding properties and presents the results of an extensive Swiss study. The study compares the bonding properties determined with the Layer Parallel Direct Shear Test (LPDS) according to Leutner of 14 high volume roads from the years 1993–97 to the values for the same road sections determined 9–13 years later. In addition, a second study conducted on a circular track investigated the differences between the bonding properties in the wheel path and outside the wheel path. It could be shown that in most cases the bond improves due to compaction and settlement caused by the traffic. Problems arise, resulting in a reduction of shear forces, when the pavement shows distress phenomena. The difference between the bonding properties in the wheel path and outside it could be demonstrated in the circular track study, whereas the differences on the road depend on many factors and often seem to be eliminated over the years.

Keywords: adhesion properties, Layer-Parallel Direct Shear (LPDS) test, interlayers.

1. Introduction

In recent years bonding testing has gained more and more importance throughout Europe (Choi *et al.* 2005, Diakhate *et al.* 2006, Kruntsheva *et al.* 2006, Tschegg *et al.* 2007). In a lot of projects the bonding properties are determined after construction and many countries have developed standard requirements which the obtained bonding values are to fulfil. The question of how the originally determined bonding properties develop over time is often neglected and has not attracted enough attention of the Road Authorities etc.

Although different researchers (Canstrari *et al.* 2005, Rabiot 1996, Stöckert 2001) showed that the bond improves with time, this finding was never investigated on a larger scale in a systematic way. In some cases (Stöckert 2001) the re-evaluation of the shear strength took place only a year after construction and therefore it cannot consider long-term effects and influences. Furthermore, the improvement of bonding properties is stated as a general fact, but no reference to traffic figures is provided.

This paper describes the results of an extensive Swiss study of the long-term behaviour of bonding properties launched by the Swiss Road Authorities (ASTRA). Based on the results directly after construction of more than 1000 cores of 20 different pavements, a decade later the

long-term bonding properties of some of these pavements could be determined again. The study compares the bonding properties determined with the Layer Parallel Direct Shear Test (LPDS) according to Leutner of 14 high-volume roads from the years 1993–97 to the values for the same road sections determined in 2006.

In addition, a second study of a circular truck investigated the differences between the bonding properties in the wheel path and outside it.

2. Testing

The Layer-Parallel Direct Shear (LPDS) test device (Fig. 1) is an EMPA modified version of equipment developed in Germany by Leutner being more versatile in the geometry and more sophisticated in the clamping mechanism (Leutner, 1979). The modified LPDS test device fits into an ordinary servo-hydraulic Marshall testing machine and allows the testing of cores with a diameter of about 150 mm and rectangular specimens; no normal force can be applied (Partl, Raab 1999; Raab, Partl 1999).

One part of the core (up to the shear plane to be tested) is laid on a circular u-bearing and held with a well defined pressure by a semicircular pneumatic clamp. The other part, the core head in Fig. 1, remains unsuspending. Shear load is

induced to the core head by a semicircular shear yoke with a deformation rate of 50,8 mm/min, thus producing fracture within the pre-defined shear plane of 5 mm width.

The specimens were conditioned in a climate chamber for 8 h and all tests were conducted at 20 °C. Since 2000 the LPDS is incorporated into the *Swiss Standard SN 67196*.

From the LPDS test, the shear force F as a function of shear deformation w is obtained. Additional to the shear force, the max slope from the diagram of shear force F versus shear deformation w can be used to define the LPDS max shear “stiffness” value $S_{LPDS,max}$ as follows:

$$S_{LPDS,max} = \frac{\Delta F}{\Delta w}, \quad (1)$$

where $S_{LPDS,max}$ – max shear “stiffness”, kN/mm; ΔF – derivative of force, kN; Δw – derivative of deformation, mm.

3. Investigation of pavements from trafficked roads

3.1. Situation and material

In 1999, a research project FA 12/94 of the interlayer adhesion of new pavement layers was completed. It was found that the direct LPDS shear test according to Leutner was a useful tool for inter-layer shear adhesion assessment (Partl, Raab 1999; Raab, Partl 1999). The question of long-term performance of the inter-layer shear bonding, in terms of the relationship between the bonding properties directly after construction and the bonding properties after some years of trafficking was only touched on in a limited way in this former project. Therefore a follow-up project was conducted entitled “Long-term performance of the bonding properties – relation between test value after construction and long-term performance” (Raab, Partl 2007). In the framework of this project, all 14 remaining sections were investigated again, after 10 or more years of traffic, in

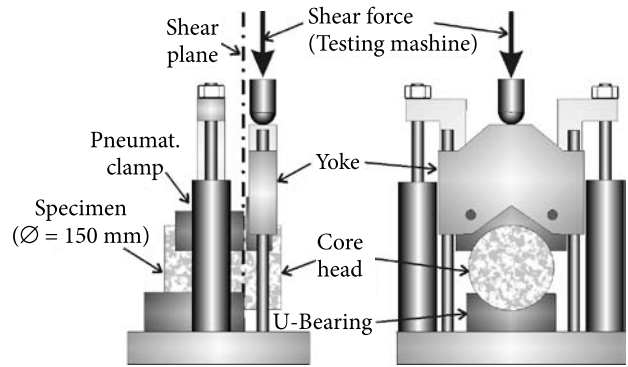


Fig. 1. LPDS test device, schematic drawing (Raab, Partl 2004)

order to predict the long-term performance of the bonding properties.

As shown in Table 1, the surface course thickness varied between 29 and 60 mm. Since the construction took place before the European Standards became effective, all terms are taken according to the old *Swiss Standard SN 640431*. 7 pavements had stone mastic asphalt (SMA) and 4 road sections had asphalt concrete (AC) surface courses. In addition, 3 coring sites with special surface courses, i.e. gussasphalt (mastic asphalt) (GA), hot-rolled asphalt (HR) and porous asphalt (drain asphalt = DRA) were included. With the exception of 3 pavements all surface courses consisted of aggregate with a max size of 11 mm. The surface courses were placed either on hot mix base course (HMT) with a max aggregate size of 16, 22 or 32 mm or on asphalt concrete (AC) and mastix asphalt (MA) with a max aggregate size of 16 mm each.

For nearly all road sections, traffic data, e. g. the average daily traffic ADT (vpd) and the percentage of heavy vehicles (> 3,5 t) are given in Table 1.

Table 1. Coring sites with pavement characteristics and traffic data (Bundesamt für Straßen ASTRA; Bundesamt für Statistik BFS 2006)

Road section	Materials		Surface course characteristics		Traffic data 2005	
	Surface course	Base course	Thickness, mm	Year of construction	Average daily traffic (ADT), vpd	Heavy vehicles (> 3,5 t), %
2	SMA 11	HMT 32	35,0	1993	–	many buses
3	SMA 11	HMT 32	30,0	1994	18 350	9,8
5	SMA 11	HMT 22	40,0	1996	32 700	7,6
6	SMA 11	HMT 16	60,0	1993	94 990	4,4
7	SMA 11	HMT 22	30,0	1994	19'800	4,4
8	SMA 11	HMT 32	41,0	1996	31 450	5,5
14	SMA 11	HMT 22	40,0	1997	28 050	5,8
10	AB 11	HMT 32	29,0	1995	77 890	11,1
15	AB 11	HMT 32	45,0	1997	64 230	8,2
18	AB 16	unknown	48,0		–	–
19	AB 16	unknown	50,0	1997	–	–
11	HR 16	HMT 22	44,0	1993	6800	2,6
12	GA 11	GA 16	43,0	1996	32 700	7,6
13	DRA 11	AB 16	45,0	1994	4,6	4,6

In the original investigation, the pavements were either totally new or a new surface course had been placed over existing layers. In 2 cases, pavements with new surface courses on unknown old base courses were investigated (coring sites 18 and 19).

The coring for investigating the long-term performance was conducted a few meters away from the original coring site. For every road section 5 cores were taken inside and another 5 outside the wheel path. In addition to the shear force at 20 °C, the max shear stiffness was determined.

3.2. Test results

Figs 2–4 depict the LPDS test results at 20 °C for the different test sections. Each Figure represents the comparison of the shear force values immediately after construction but before traffic and the shear force values after several years of traffic. In case of the values immediately after construction and before traffic all bars are mean values of at least 7 specimens. In case of the values after several years of traffic the mean value of all 10 cores is given, as well as the mean value of 5 specimens in the wheel path and 5 specimens outside the wheel path. The standard deviation is also presented.

For the SMA surface courses in Fig. 2 all test sections were between 9 and 13 years old and therefore quite comparable. Except for one section (road section 3), which showed severe rutting in the wheel path, the pavement surfaces of all other sections were in good condition and did not reveal surface distresses.

Apart from section 3 and section 6, a slight (9–14 %) to great (28–45 %) improvement of the shear forces over time could be observed for all sections. Although the mean value after trafficking was low, it is remarkable that section 3 had shear forces outside the wheel path which were by 12,7 % higher than directly after construction.

Section 6 was the only coring site, where an overall deterioration of the shear forces (ca. 31 %) over time could be found.

For the great majority of road sections (4 sections) there was only a small difference between the shear forces inside and outside the wheel path, whereas in two cases the values in the wheel path were higher and in two other cases the ones outside the wheel path were higher. One section (section 2) subjected to a heavy bus traffic showed a 5 kN lower shear force in the wheel path than outside the path.

The data for the road sections with SMA surface courses showed that in the wheel path an improvement of the shear force could not always be expected, but even the opposite was true.

For the AC surface courses in Fig. 3 all test sections were between 9 and 13 years old, therefore in this respect quite comparable. All investigated road sections except one (section 15), which revealed cracks and aggregate loss, showed an intact pavement surface.

The shear forces for all road sections with AC surface courses were 7 % and 23 % higher after several years. For the above-mentioned road section 15, where aggregate loss and cracking occurred, the shear forces in the wheel path were by 35 % lower than those directly after construc-

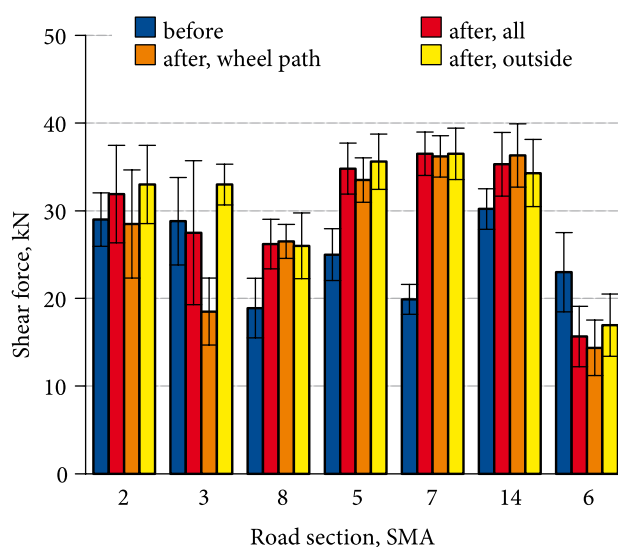


Fig. 2. Comparison of shear forces at 20 °C directly after construction and after several years of traffic for all road sections with SMA surface course

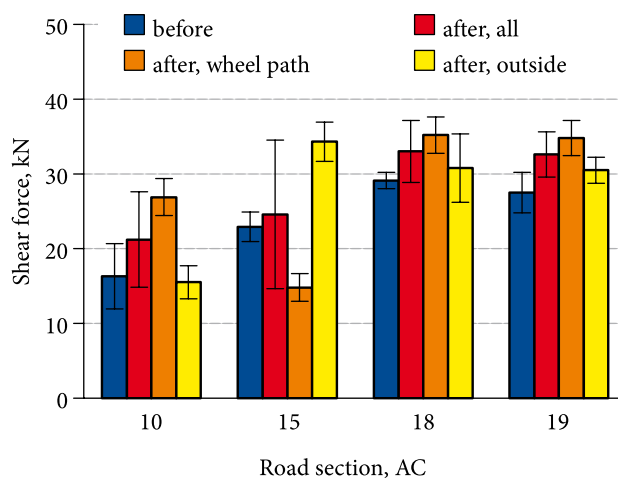


Fig. 3. Comparison of shear forces at 20 °C directly after construction and after several years of traffic for all road sections with AC surface courses

tion, whereas the values outside the wheel path were by 33 % higher than before traffic.

In contrast to the road sections with SMA surface courses, all the sections with AC surface courses showed an improvement of the values in the wheel path of 17–39 % – noticeably higher than those outside the wheel path, where the increase was only 5–10 %.

Fig. 4 shows the result for the HR, GA and DRA surface courses which were 13, 12 and 10 years old and showed no surface distresses. For 3 road sections an improvement of the bonding properties of 12,2 %, 6,9 % and 45,2 % could be observed. For the sections with GA and DRA no significant difference between the shear forces in and outside the wheel path could be found. For the HR section, the shear forces outside the wheel path were by 30 % higher than the values directly after construc-

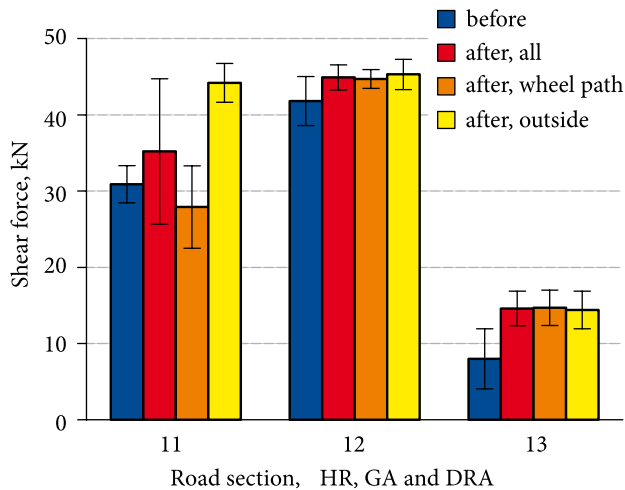


Fig. 4. Comparison of shear forces at 20 °C directly after construction and after several years of traffic for all road sections with HR, GA and DRA surface courses

compared to the values in the wheel path, which only showed an improvement of 10 %.

Fig. 5 depicts the shear stiffness at 20 °C directly after construction and after several years of traffic. As an example, the results for all road sections with SMA surface courses are shown.

It is clear that the shear stiffness increased in the course of the years between 9–45 %. However, it can not be demonstrated in which way the position of the cores – in or outside the wheel path – had an influence on the shear stiffness, since in some cases the stiffness in the wheel path was higher and in others it was lower.

For sections 3 and 6, where decreasing shear force values had been found, the increase of the shear stiffness was lower than in other sections.

The comparison of the situation immediately after construction with the situation after 9 to 13 years of traffic reveals an increase in shear force between surface and base course of 7–45 %. Of 14 sections only 2 sections showed a decrease in the average shear force (4,5 and 32 %). While the pavement of one section (section 3) showed rutting and an increase of the average shear force outside the wheel path, no optical reason could be found for the decrease observed for the second section (section 6).

As soon as pavements show surface distresses such as rutting or cracking, the average shear forces after some years of traffic decrease in and in some cases outside the wheel path.

The traffic figures given in Table 1 are quite different for all sections. This is not only true for the ADT but also for the percentage of heavy vehicles (trucks > 3,5 t). These percentages vary between 2,6–11 %.

Regarding ADT and percentage of heavy vehicles, sections 6, 10 and 15 are the most critical ones. The measured shear forces of these sections demonstrate that a high percentage of heavy vehicles over a long period of time can cause bonding problems: Section 15 reveals severe pavement distresses and decreased shear forces in the wheel

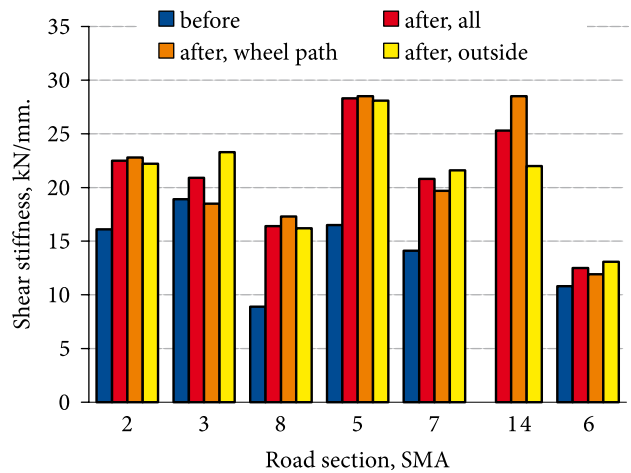


Fig. 5. Comparison of shear stiffness at 20 °C directly after construction and after several years of traffic for all road sections with SMA surface courses

path. For section 10 the shear forces outside the wheel path are lower than immediately after construction. On the other hand, Section 6 is the only section which shows a decrease of shear forces despite its intact pavement surface.

In addition, section 3, with severe rutting and a deterioration of the bonding properties in the wheel path, has a very high percentage of heavy traffic, especially for a city road. Although there are no traffic figures given for section 2, this section is located near a bus stop and is therefore highly frequented by buses.

4. Investigation of pavements from a circular track

4.1. Situation and material

In the second study, conducted on a circular test track, the differences of bonding properties in the wheel path and outside the wheel path were investigated.

In the framework of another research project, different materials have been placed in a circular track and were traffic over a certain time (Rabaiotti, Caprez 2006). Although for these materials no values directly after construction were available, the project was considered ideal for investigating bonding properties in and outside the wheel path, since, as opposed to the situation on a real road, traffic happens in a very defined, canalised manner. The material was placed in 5 sections with a length of 20 m as shown in Fig. 6. The pavement details of the different sections are in Table 2.

As shown in Table 2, all surface courses consist of identical asphalt concrete, AC 11, with a penetration grade binder of 50/70. The hot mix base courses, AC T 22, differ from each other in binder type. For section 5, a high modulus binder base course, AC EME (enrobé à module élevé), was used. The exact description of the materials in (Rabaiotti, Caprez 2006).



Fig 6. Circular track

Table 2. Material used in the test section on the circular track (Rabaiotti, Caprez 2006)

Section	Material	
	Surface course	Base course
U1	AC 11S B50/70	AC T 22S B50/70
U2	AC 11S B50/70	AC T 22S B50/70
U3	AC 11S B50/70	AC T 22S B70/100
U4	AC 11S B50/70	AC T 22S Styrelf C85
U5	AC 11S B50/70	AC T 22S EME 2

4.2. Test results

The test results for the LPDS test at 20 °C for different sections on the circular track are shown in Fig. 7. Fig. 8 depicts the air void content determined on cores taken from the different section in and outside the wheel path.

With mean values between 36,6–45 kN the obtained interlayer shear forces were very high. The comparison between the different sections reveals that the results for sections 1 and 2 with the same materials correspond very well with shear force values of 38 kN and 36 kN. Section 3 with a softer binder in the base course shows a slightly higher shear force of 42 kN, which is comparable to section 5, where a value of 43 kN was found. The highest value of 45 kN was received for section 4, where a polymer modified bitumen was used in the base course.

In general, the investigation demonstrates the differences in the shear forces in and outside the wheel path. This can be directly linked with the different compaction and air void content in these areas (Fig. 8), which is on a circular track more uneven than on a straight road.

5. Conclusions

As the results of this extensive Swiss study on long-term behaviour of bonding properties, the following main conclusions can be drawn.

1. The traffic induced compaction and settlement after construction has a positive effect on bonding properties of

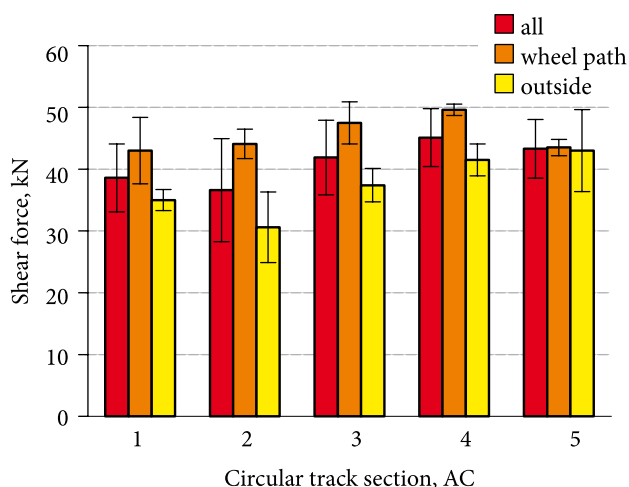


Fig. 7. LPDS test results at 20 °C for the circular track, mean values and standard deviation

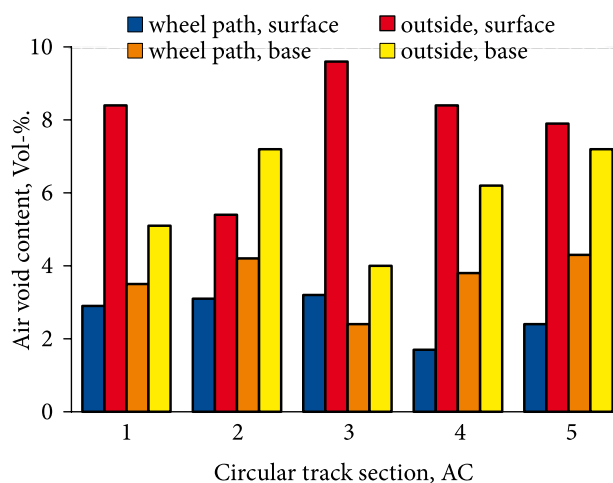


Fig. 8. Air void content of surface and base course in and outside the wheel path for the circular track sections

carefully designed and manufactured roads. The increase in shear resistance in terms of shear force between surface and base course can reach 40 % after 10 years. In terms of shear stiffness the increase can go even up to 57 %.

2. Pavements showing distress phenomena, such as cracks and aggregate loss, have a high potential to suffer also a reduction of interlayer shear resistance, especially in the wheel path.

3. As long as the road does not show obvious surface distresses, differences between interlayer shear force and stiffness inside and outside the wheel path are generally not expected; however, they may occur in special cases where a local change in performance, such as rutting and cracking, is clearly predominant.

4. As soon as pavements show surface distresses such as rutting or cracking, the average shear forces and shear stiffness values after some years of traffic decrease and in some cases also outside the wheel path.

5. A high percentage of heavy vehicles over a long period of time can cause bonding problems.

6. Behaviour on roads can divert substantially from test pavement sections that are tested under extreme conditions in stationary accelerated pavement testing facilities, such as circular test tracks. This is partly due to the different compactions and air voids in the track sections resulting from special construction conditions and equipment as well as the more canalized accelerated loading which does not leave much potential for mobilizing healing effects.

This investigation provides a valuable quantitative practical input, e.g. for standardization purposes. It shows that interlayer shear properties are clearly subjected to change over the life-time of a pavement. Hence, further investigations will also have to focus on the continuous monitoring of the whole process of change, i.e. the development of interlayer properties over time as a function of traffic and climatic history as well as of the evolution of volumetric and chemical-physical properties. This future task will certainly not only be a challenge in modeling but also in sensing and monitoring techniques.

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