

EVALUATION OF INTERLAYER SHEAR BOND DEVICES  
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**Abstract.** For testing the bond between asphalt pavement layers quite a variety of methods were proposed and used during the last 30 years. In many publications some of these test methods and devices were described by presenting photographs and sketches. Often photographs show the functioning of the devices only insufficiently and detailed information regarding the test devices (e.g. gap width) and test conditions (e.g. loading function, normal force) are difficult to retrieve. The following paper summarises the test methods and devices for the determination of the bond between asphalt pavement layers regarding shear testing. Direct and simple shear tests from all over the world are presented and their mode of operation shown. Furthermore, the range of applications is described and information regarding test evaluation and results are given.

**Keywords:** interlayer bond test devices, direct and simple shear tests, asphalt pavements.

## 1. Introduction

Due to the increasing demands of the road users as well as increasing rehabilitation costs and decreasing budgets the design and construction of long lasting asphalt pavements is becoming more and more important. Extensive research efforts are still under way world-wide, focusing on the optimisation of the mechanical properties of mixes in the individual layers. However, it was often neglected that not only the material properties of the individual layers but also the interlayer bond play an important role in achieving optimal long-term structural performance of a pavement (Raab, Partl 2004).

As shown in Fig. 1 the bond between asphalt layers is extremely important for the bearing capacity and the long term performance of pavements, a fact that has become more widely accepted during recent years and led to adhesion testing as a subject of study and a development of many different test methods and procedures to evaluate the bond between pavement layers over the last decades.

The reason why it has taken long to formulate qualitative requirements for the bond between the layers of an asphalt pavement may certainly have to do with the great number of parameters influencing this bond as well as their interactions. The complexity of these interactions is also the reason for the difficulties to quantify the single parameters. Fig. 2 names some of the most important parameters for a durable bond between the layers. By listing the

different parameters separately it becomes clear that there are many interactions between them. For example mineral aggregate size, binder properties and mixture composition are influenced by the chosen pavement type, while they are responsible of the friction and the interlock properties.

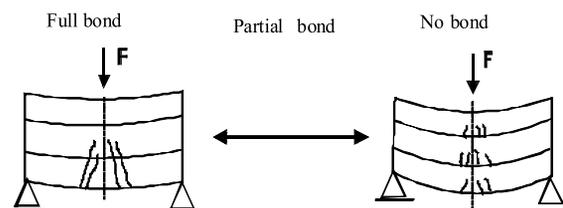


Fig 1. Redistribution of stresses in a single multilayered system due to the loss of adhesion between the layers

Consequently it is not surprising that a lot of different methods have been proposed to determine the bond between pavement systems. The following figure (Fig. 3) gives a schematic overview of possible test methods and their application ranges.

The choice of a certain test methods depends on the assumed loading mode and the type of application (e.g. in-situ, laboratory), the problem area (e.g. bond failure due to tensile stresses, such blisters or failure due to shear stresses) as well as the accuracy and repeatability of a certain test method.

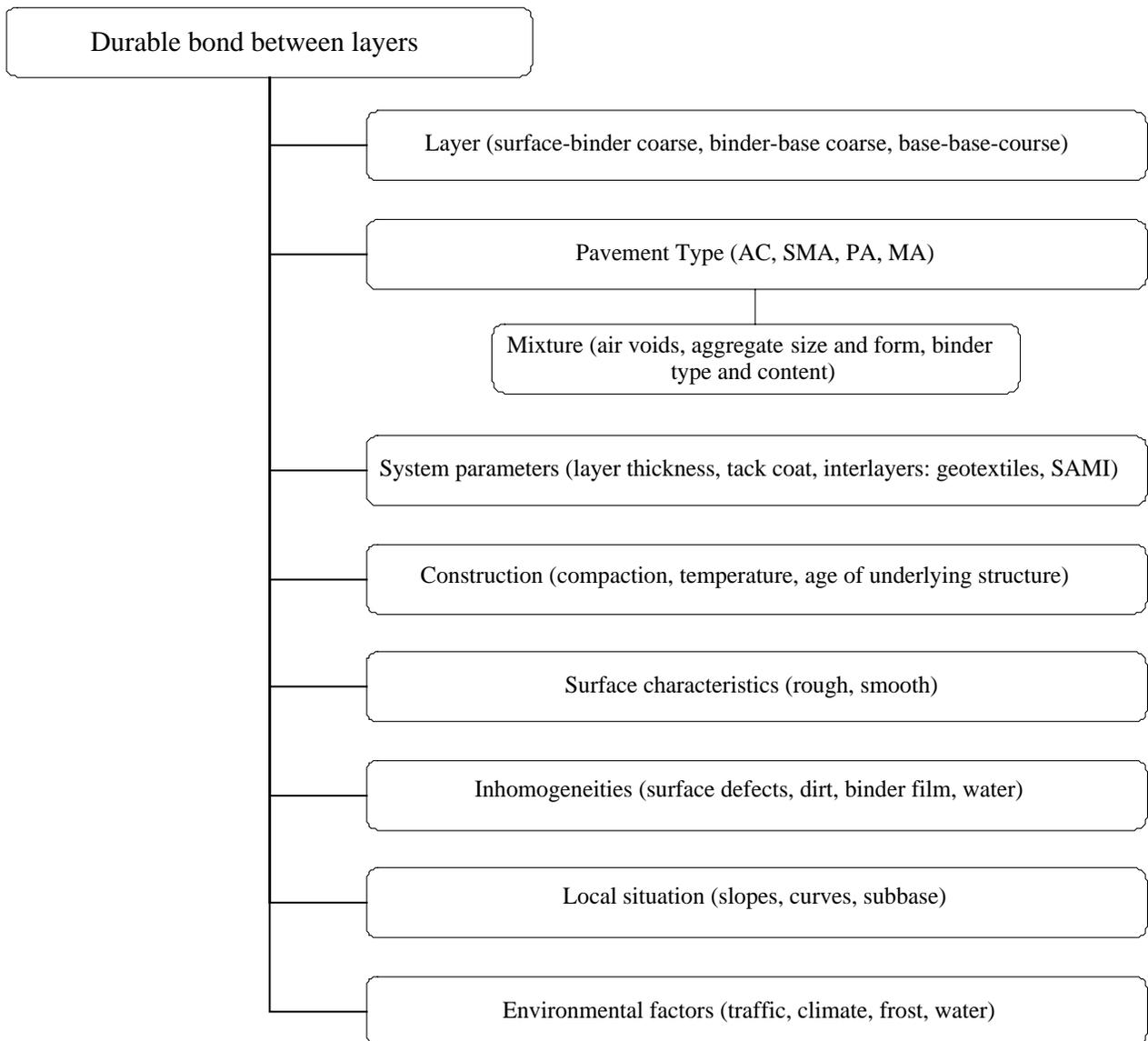


Fig 2. Factors influencing a durable bond between layers

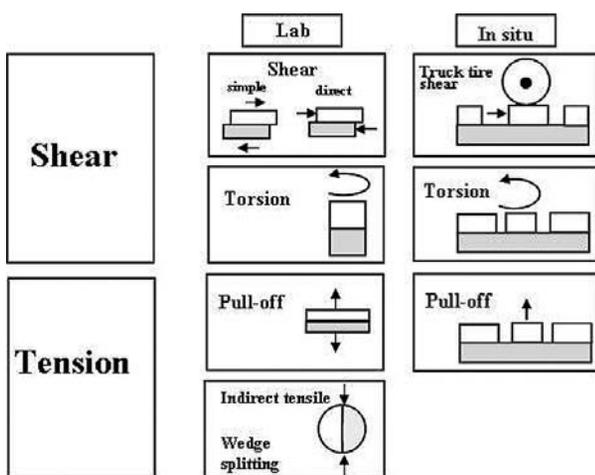


Fig 3. Test methods to determine interlayer bond properties in the lab and in the field (Raab, Partl 1999)

During recent years many European countries as well as the United States and Canada have established methods and equipment for testing the interlayer bond. On the one hand, there are methods commonly used in different countries, such as the Leutner shear test (Leutner 1979) which was taken into the national test specifications in Germany shortly after its standardisation in Switzerland and Austria. On the other hand specific solutions such as the wedge splitting test (Tschegg *et al.* 2007) or the torsion test British Board of Agreement (BBA). Guideline document for the assessment and certification of thin surfacing systems for highways, 2004, Choi *et al.* 2005) were proposed. In Italy the ASTRA shear apparatus (Canestrari, Santagata 2005) was developed and will shortly become a national specification. In the USA interlayer bond testing has become a serious issue. As a potential option for testing the bond between asphalt layers, (Mohammad *et al.* 2002) designed a custom made shearing apparatus for use in the Superpave Shear Tester. In Canada, Carleton Uni-

versity, has also been working for many years on the development of an in-situ shear tester (Abd El Halim 2004).

The different test methods, including the various equipment, have been presented in numerous publications (Canestrari *et al.* 2005; Kruntcheva *et al.* 2006; Raab, Partl 1999; Stöckert 2001; West *et al.* 2005) in such a way that photographs of the various devices are depicted. But often from these photographs the functioning of the devices is not too clear and detailed information regarding test devices (e.g. gap width) and test conditions (e.g. loading function, normal force) are difficult to obtain.

The following paper tries to give a more complete overall overview of the most important test method for interlayer bond testing, the shear testing, highlighting the differences in terms of test devices, testing specifications and test results for the different devices and countries. The concentration on shear testing was chosen since that test method has been by far the most common method to determine the bond between asphalt pavements. Although, there are many different devices, some of them have already been standardised and common test specifications (deformation rate, test temperature) have already existed in a few countries for some time.

## 2. Shear testing

The construction of shear testing devices for asphalt pavements originally was derived from shear testing in soil mechanics and already in the late 1970ies different equipments such as the Leutner test (Leutner 1979) in Germany or similar tests in the US were developed (Uzan *et al.* 1978). There are two fundamentally different systems: the direct and the simple shear test.

The direct shear test, in general, is a guillotine type test where the shear force is induced directly at one side part and not at the front surface of the specimen (Fig. 4).

The direct shear testing devices, as depicted in Tables 1 and 2, can be divided in devices which use a clamping or fitting system to hold the test specimen (Partl, Raab 1999; Romanoschi, Metcalf 2002; Sholar *et al.* 2004; West *et al.* 2005; Zeng *et al.* 2008) and devices which utilize a bending mechanism (3 or 4 point shear tests) to apply the shearing (De Bondt 1999; Miro Recasens *et al.* 2003).

In the simple shear tests (Table 3) the upper part of the test specimen is sheared against the bottom part of the test specimen and the shear force is induced at the specimen front surface of the specimen. In the case of a three layered specimens (De La Roche 1996; Milien *et al.* 1996) the middle part is sheared against both outer parts. For the simple shear test, as depicted in Table 3 the mechanism of the different devices is similar, differing mainly in the way the shear forces are applied and how both parts of the test specimen are moved against each other (Canestrari *et al.* 2005; Sanders *et al.* 1999).

As opposed to the direct shear tests, where the test specimens can either be clamped or fitted into steel moulds, the test specimens in the simple shear test are always fitted into the shear mould by glue or tight fixtures. Therefore, here the application of a normal force vertical to the shear plane is always an option. Whereas in shear test devices using clamping mechanisms, normal forces are often not taken into consideration. Another possibility to include a normal force was developed by Romanoschi whose testing device allowed for the longitudinal axis of the test specimen being at a 25.5° angle with the vertical (Romanoschi, Metcalf 2001).

While some shear tests, mainly the ones used of quality assessment, only allow for static testing, others can be used either in a static or a dynamic mode (Ascher, Wellner 2007; Crispino *et al.* 1997; Romanoschi, Metcalf 2002; Sanders *et al.* 1999).

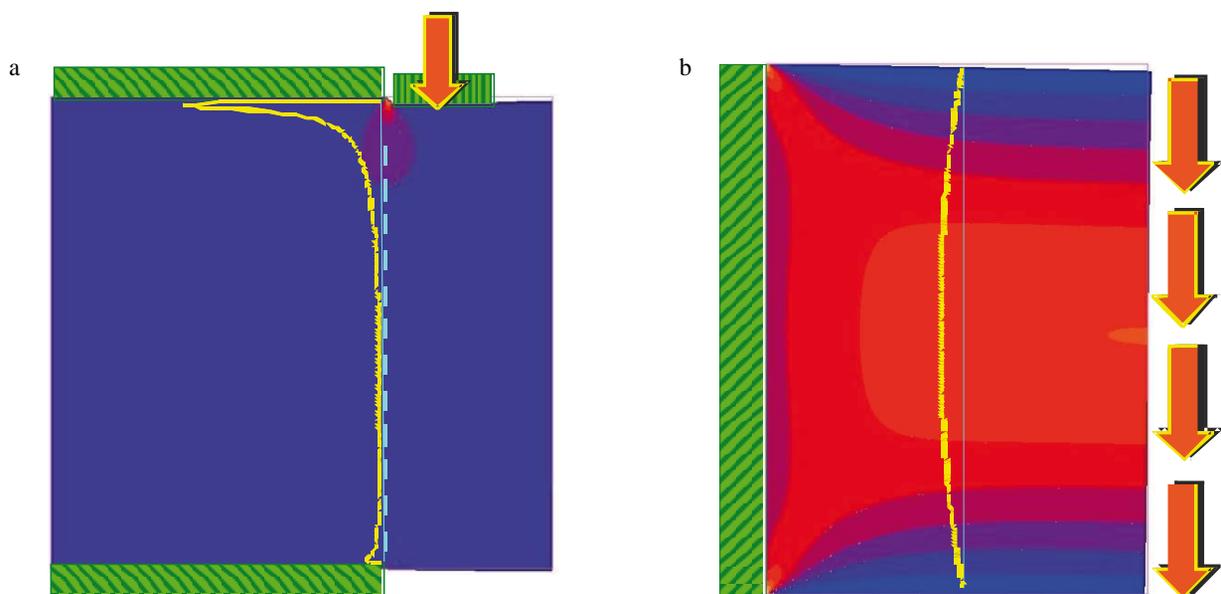


Fig 4. Shear stress distribution at the specimen head in the direct shear test (a), shear stress distribution in the direct shear test (b)

**Table 1.** Direct shear test devices (1)

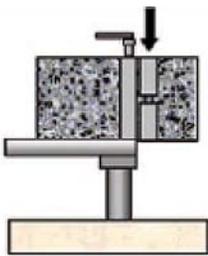
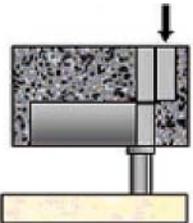
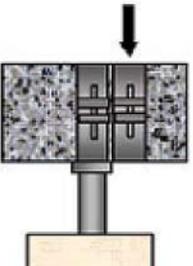
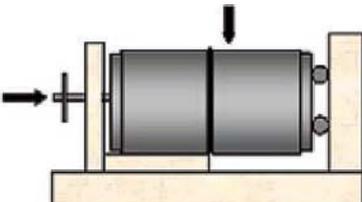
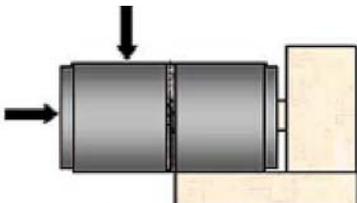
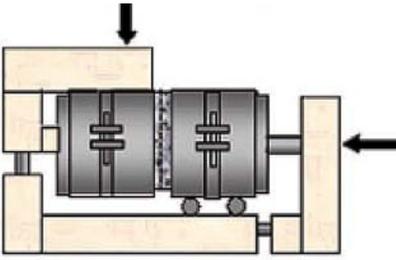
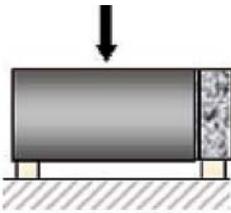
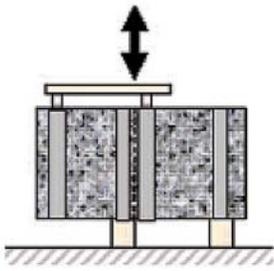
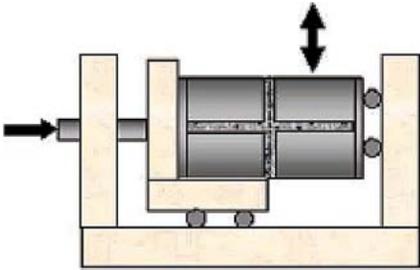
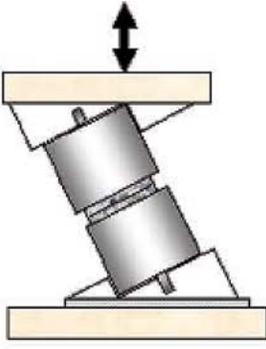
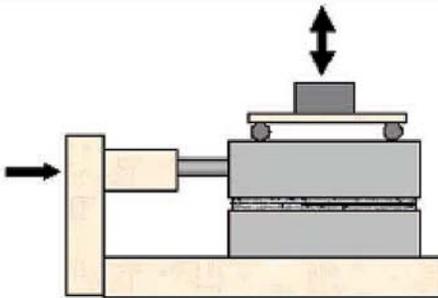
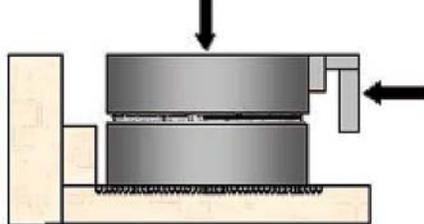
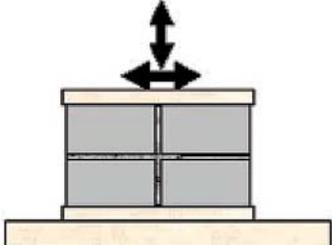
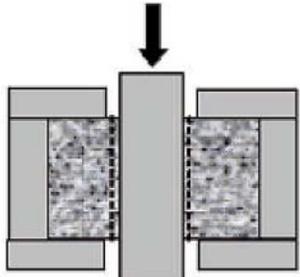
Device	Characteristics
 <p data-bbox="278 570 425 597">Leutner device</p>	<p data-bbox="582 268 1345 321">Specimens: cylinders 150 mm or 100 mm (Austria), specimens are mechanically clamped with a latch fastener</p> <p data-bbox="582 331 751 359">Gap width: 1 mm</p> <p data-bbox="582 370 714 397">Testing: static</p> <p data-bbox="582 408 771 436">Normal force: none</p> <p data-bbox="582 446 1364 500">Method for quality control in different European countries (e.g. Austria, Germany and Switzerland)</p> <p data-bbox="582 510 874 538">Deformation rate: 50 mm/min</p> <p data-bbox="582 549 1136 576">Temperature: 20 °C (standard), for research 10 °C to 40 °C</p> <p data-bbox="582 587 1090 614">Result: force/deformation diagram, max force (stress)</p>
 <p data-bbox="240 932 463 959">Modified device, Empa</p>	<p data-bbox="582 644 1395 719">Specimens: grinders 150 mm (standard), others: 148 mm to 155 mm, and rectangular specimens 150×130 mm, specimens are hold by defined pneumatic pressure using a semicircular damp</p> <p data-bbox="582 729 751 757">Gap width: 2 mm</p> <p data-bbox="582 768 714 795">Testing: static</p> <p data-bbox="582 806 874 834">Deformation rate: 50 mm/min</p> <p data-bbox="582 844 771 872">Normal force: none</p> <p data-bbox="582 883 1110 910">Temperature: 20 °C (standard), other for research 40 °C</p> <p data-bbox="582 921 1379 974">Result: force deformation diagram, max force (stress), stiffness (max force/max slop of the force/deformation curve) in kN/mm</p>
 <p data-bbox="286 1325 409 1353">Iowa device</p>	<p data-bbox="582 1038 1349 1091">Specimens: cylinders 150 mm, specimens are fixed in aluminium rings with pipe clamps</p> <p data-bbox="582 1102 766 1129">Gap width: 4.8 mm</p> <p data-bbox="582 1140 714 1168">Testing: static</p> <p data-bbox="582 1178 771 1206">Normal force: none</p> <p data-bbox="582 1217 874 1244">Deformation rate: 50 mm/min</p> <p data-bbox="582 1255 766 1283">Temperature: 25 °C</p> <p data-bbox="582 1293 1090 1321">Result: force deformation diagram, max force (stress)</p>
 <p data-bbox="286 1634 417 1661">NCAT device</p>	<p data-bbox="582 1378 1279 1406">Specimens: cylinders 150 mm, specimens are cut and placed in steel cups</p> <p data-bbox="582 1417 766 1444">Gap width: 4.8 mm</p> <p data-bbox="582 1455 714 1483">Testing: static</p> <p data-bbox="582 1493 1372 1547">Normal force: 0 to 550 kPa, applied by screwing the front pressure plate to the steel cups using a latch fastener</p> <p data-bbox="582 1557 867 1585">Defomation rate: 50 mm/min</p> <p data-bbox="582 1596 894 1623">Temperature: 10 °C, 25 °C, 60 °C</p> <p data-bbox="582 1634 1090 1661">Result: force deformation diagram, max force (stress)</p>
 <p data-bbox="263 1938 440 1966">Romanoshi device</p>	<p data-bbox="582 1698 1267 1725">Specimens: cylinders 95 mm, specimens are cut and placed in steel cups</p> <p data-bbox="582 1736 751 1764">Gap width: 5 mm</p> <p data-bbox="582 1774 714 1802">Testing: static</p> <p data-bbox="582 1813 837 1840">Normal force: 0 to 550 kPa</p> <p data-bbox="582 1851 867 1879">Defomation rate: 12 mm/min</p> <p data-bbox="582 1889 894 1917">Temperature: 15 °C, 25 °C, 35 °C</p> <p data-bbox="582 1927 1090 1955">Result: force deformation diagram, max force (stress)</p>

Table 2. Direct shear test devices (2)

Device	Characteristics
 <p data-bbox="304 549 452 576">Al-Qadi device</p>	<p data-bbox="632 314 1325 342">Specimens: cylinders 100 mm, specimens are cut and placed in steel cups</p> <p data-bbox="632 353 763 380">Testing: static</p> <p data-bbox="632 391 848 419">Normal force: possible</p> <p data-bbox="632 429 922 457">Deformation rate: 12 mm/min</p> <p data-bbox="632 468 945 495">Temperature: 10 °C, 20 °C, 30 °C</p> <p data-bbox="632 506 1136 534">Result: force deformation diagram, max force (stress)</p>
 <p data-bbox="324 825 432 853">LBC device</p>	<p data-bbox="632 619 1241 646">Specimens: cylinders 100 mm, specimens are placed in steel cup</p> <p data-bbox="632 657 763 685">Testing: static</p> <p data-bbox="632 695 817 723">Normal force: none</p> <p data-bbox="632 734 940 761">Deformation rate: 1.27 mm/min</p> <p data-bbox="632 772 890 800">Temperature: 5 °C to 45 °C</p> <p data-bbox="632 810 1136 838">Result: force deformation diagram, max force (stress)</p>
 <p data-bbox="298 1172 458 1200">De Bondt device</p>	<p data-bbox="632 944 1118 972">Specimens: prismatic specimens 450×100×125 mm</p> <p data-bbox="632 983 890 1010">Testing: static and dynamic</p> <p data-bbox="632 1021 917 1049">Normal force: none (possible)</p> <p data-bbox="632 1059 964 1108">Loading function: <math>\frac{\tau}{\tau_f} = 0.25, 8 \text{ Hz}</math></p> <p data-bbox="632 1108 1171 1136">Result: force along contact plane-slip along contact plane</p>
 <p data-bbox="320 1513 443 1540">Asher device</p>	<p data-bbox="632 1221 1356 1249">Specimens: cylinders 100 mm, specimen are glued into two steel semicircles</p> <p data-bbox="632 1259 853 1287">Gap width: 0 to 15 mm</p> <p data-bbox="632 1298 797 1325">Testing: dynamic</p> <p data-bbox="632 1336 914 1364">Normal force: 0–1.11 N/mm<sup>2</sup></p> <p data-bbox="632 1374 1395 1427">Loading function: sinusoidal with amplitudes of 0.005 to 0.1 mm and frequency of 1–15 Hz</p> <p data-bbox="632 1438 910 1466">Temperature: -10 °C to 30 °C</p> <p data-bbox="632 1476 1321 1534">Result: force time diagram and deformation time diagram, AK = relative deformation between layers/shear stress between layers in m<sup>3</sup>/N</p>
 <p data-bbox="247 1932 509 1959">Romanoshi dynamic device</p>	<p data-bbox="632 1561 1402 1619">Specimens: cylinders 100 mm, specimen are fixed into steel cups, longitudinal axis of the specimen is at 25.5° with the vertical axis</p> <p data-bbox="632 1630 797 1657">Testing: dynamic</p> <p data-bbox="632 1668 1025 1696">Normal force: 0.5, 0.75, 1.0 and 1.25 MPa</p> <p data-bbox="632 1706 1367 1759">Loading conditions: vertical load 10% of max load, frequency of 5 Hz, total period of 0.2 s, length of pulse of 0.05 s (simulating a vehicle pass at 50 km/h)</p> <p data-bbox="632 1770 817 1798">Temperature: 25 °C</p> <p data-bbox="632 1808 1402 1953">Result: elastic and permanent displacements at the interface in normal and tangential directions for each cycle; dynamic tests were stopped when the permanent shear displacement (PSD) at the interlace reached 6 mm or when it was considered that the number of cycles corresponding to a PSD of 6 mm could be extrapolated.</p>

**Table 3.** Simple shear test devices

Device	Characteristics
 <p style="text-align: center;">Shear box</p>	<p>Specimens: prismatic (320×200 mm), specimens are in the mould fixed using an epoxy glue</p> <p>Gap width: approx 10–20 times the mean particle diameter of the test specimen</p> <p>Testing: dynamic and static, if dynamic test does not result in failure</p> <p>Deformation rate: 1.5 mm/min</p> <p>Normal force: applied servo hydraulically, 0, 50, 100, 200 and 250 kN/m<sup>2</sup></p> <p>Loading function: sinusoidal shear stress with frequency of 2 Hz, vertical load 200 kN/m<sup>2</sup>. While vertical stress was kept constant, shear stress was increased in 5 levels until the specimen fails; if the specimen did not fail during dynamic testing, a static test was performed with constant deformation rate.</p> <p>Result: dynamic shear stress-relative displacement diagram</p>
 <p style="text-align: center;">ASTRA device</p>	<p>Specimens: rectangular, max cross section of 100×100 mm and cylindrical with diameters 95 to 99 mm, specimen are fixed in two steel cups</p> <p>Gap width: diameter of particle diameter of the test specimen</p> <p>Testing: static</p> <p>Normal force: 0, 0.2 and 0.4 MPa, applied by a lever and weight system</p> <p>Deformation rate: 2.5 mm/min</p> <p>Temperature: variable in climatic chamber</p> <p>Result: data-file with shear force <math>T</math>, horizontal <math>\xi</math> and vertical <math>\eta</math> displacement related to time</p>
 <p style="text-align: center;">SHRP shear test device SST</p>	<p>Specimens: cylindrical with Ø150 mm, specimen are glued onto aluminum “caps”</p> <p>Testing: static or dynamic</p> <p>Loading function: constant load mode (222.4 N/min)</p> <p>Normal force: none, possible</p> <p>Temperature: 25 °C and 55 °C</p> <p>Result: shear stress-deformation diagram</p>
 <p style="text-align: center;">MCS device</p>	<p>Specimens: three layered specimens test specimens with the dimension of 70×100×30 mm, specimen are placed in a metal frame where the side parts of the sample are fixed while the central part is subjected to a sinusoidal displacement</p> <p>Testing: dynamic</p> <p>Loading function: sinusoidal displacement, 1 Hz</p> <p>Normal force: none</p> <p>Temperature: 5 °C</p> <p>Result: shear force time and deformation time diagrams</p>

Since in Europe most direct shear devices were designed to be mounted in a servo-hydraulic Marshall testing machine, the tests were normally conducted deformation controlled at a rate of 50 mm/min.

Mostly, cylindrical test specimens of 100 mm (Austria) or 150 mm (Germany, Switzerland) taken either directly from the road or laboratory specimens were tested (Stöckert 2001). Some devices, such as the modified Empa direct shear device LPDS, could also be used to measure the bonding of rectangular test specimens (Raab, Partl 2007). Normally the specimens were conditioned at test temperatures between 20 °C and 25 °C. Only in the case of research projects have other temperatures of between 10 °C and 40 °C been looked at (Partl, Raab 1999). However, they were found inappropriate for quality assessment, since the higher the temperature, the more difficult to find distinct differences between the different asphalt pavements. Furthermore, specimens may already be damaged during conditioning or during testing (clamping of the specimen).

Most European countries (besides Germany, Austria, Switzerland and the UK) adopted the Leutner equipment, modifying it slightly, for quality assurance of construction sites (Austrian Standard *RVS 8S.04.11: 2004*) Bending type test set ups were developed for research purposes in Spain and the Netherlands (De Bondt 1999). The Spanish device known as the LCB shear test was developed at the Technical University of Catalonia, Spain (Miro Recasens et al. 2003). Here, cylindrical test specimens were tested at a deformation rate of only 1.27 mm/min. At Delft University in the Netherlands de Bondt (De Bondt 1999) developed a four point shear test where bending effects were minimized through special arrangement of loading and supporting points.

At the Technical University of Dresden the development of a dynamic version of the Leutner shear test, is under way. This dynamic device was constructed by Ascher and also allows for a normal force (Ascher, Wellner 2007). In the dynamic testing of the bond different parameters such as temperature (−10 °C, +10 °C and +30 °C), normal load (0 to 1.11 N/mm<sup>2</sup>) and the loading function (sinusoidal function with amplitudes from 0.005 to 0.1 mm and a frequency from 1 to 15 Hz) were included. The purpose of the project was to find a “bonding factor” which can be used for pavement design in BISAR or in finite element programs.

For the simple shear test deformation rates between 1.5 mm/min in the UK (Sanders et al. 1999), and 2.5 mm/min in Italy (Canestrari, Santagata 2005) were used. In the UK the direct shear test was normally conducted in the dynamic mode, where the specimens were tested under a sinusoidal shear stress with a frequency of 2 Hz. While the vertical stress was kept constant at 200 kN/m<sup>2</sup>, the shear stress was increased in 5 levels (50, 100, 200 and 250 kN/m<sup>2</sup>) until the specimen failed. If the specimen did not fail during dynamic testing, a static test was performed using the above mentioned deformation rate of 1.5 mm/min. In Italy shear tests were conducted in a static mode using different normal loads (0, 0.2 and 0.4 MPa).

The specimens in the simple shear test, were found to be either prismatic (320×200 mm) (Sanders et al. 1999) or rectangular (max cross section of 100×100 mm) and cylindrical with a diameter between 95 mm and 99 mm (Canestrari et al. 2005).

A simple dynamic shear test for glued three layered specimens, known the Modified Compact Shearing (MCS) test (Millien et al. 1996; Diakhate et al. 2006) was developed at the Laboratory “Mechanic and Modelling of Materials and Structures in Civil Engineering (3MsCE) of the University of Limoges in France. The device allowed conducting static or dynamic tests on glued three layered specimens test specimens with the dimension of 70×100×30 mm. The specimen was placed in a metal frame where the side parts of the sample are fixed while its central part was subjected to a sinusoidal displacement, causing a shear force at both interfaces. The aim of the test program was the investigation of shear fatigue tests of asphalt concrete layer interfaces with emulsions at a constant temperature of 5 °C and a frequency of 1 Hz.

In the US direct shear testing was generally used in quality assessments and research projects, where the main focus was on the evaluation of bonding properties of different tack coat types and tack coat application rates. Different DOTs, asphalt pavement institutes or universities evaluated or modified various guillotine type shear test devices using different clamping and fixing mechanism (Leng et al. 2008; Sholar et al. 2004; West et al. 2005). As depicted in Table 1 the device differed in the fixing mechanism of the specimen as well as in the specimen diameter and the deformation rate of the testing machine. The Iowa Department of Transportation shearing device, a modification of the shearing device for Portland Cement Concrete (PCC) (*Test Method No. IOWA 406-B Method of Test for Determining the Shearing Strength of Bonded Concrete* by Iowa Department of Transportation Highway Division), was built for 100 mm diameter cylindrical specimens (either roadway cores or laboratory specimens) and with a gap width of 3.175 mm between its steel shearing platens. Further modifications used aluminium rings of 150 mm and a width of 4.8 mm between them to hold the specimen (Sholar et al. 2004).

Some devices, such as the so called NCAT bond strength device (West et al. 2005), where the specimen was held in a metal half cups, also allowed the application of normal forces, which were chosen between 0 and 550 kPa (80 psi). For direct shear testing, specimen diameter generally varied between 95 mm and 150 mm and the deformation rate between 2.5 mm/min, 12 mm/min and 50 mm/min, often depending on the available testing machine.

In the course of another research project Romanoschi (Romanoschi, Metcalf 2002) used a direct shear test device with normal load. The cores (Ø 95 mm) were first fixed in a steel split ring, with the interface positioned at the end of the ring. The half outside the steel ring was then placed and fixed in a steel cup positioned vertically and welded to a vertical supporting plate. The position of the interface was adjusted at the rim of the cup us-

ing a screwing piston placed inside the cup. To generate the shear at the interface, the vertical actuator pushed on top of the steel split ring with the constant displacement (12 mm/min) until a shear displacement of 12 mm was reached. To this day in the United States different modified Leutner type shear test devices such as (Leng *et al.* 2008) have been developed and various research projects are still underway. For his research Al-Qadi (Leng *et al.* 2008) developed a fixture where the test specimens were housed in a special steel camber with a diameter of about 100 mm. The device was designed to apply shear force in the vertical direction and normal force in the horizontal.

To simulate the repetitive load of moving vehicles, in another study Romanoschi and Metcalf (2002) proposed a test configuration to conduct shear fatigue tests on asphalt concrete layer interfaces. The longitudinal axis of the specimen was tilted 25.5° to the vertical. A vertical load was applied with 10% of the max load and with a frequency of 5 Hz. So, the total period was 0.2 s and the length of the pulse was 0.05 s, simulating the pass of a vehicle at 50 km/h. The corresponding normal stresses at the interface, 0.5, 0.75, 1.0 and 1.25 MPa were within the range of normal stress values for interfaces of road and airfield pavements.

The elastic and permanent displacements at the interface in normal and tangential directions were recorded for each cycle and the dynamic tests were stopped when the permanent shear displacement (PSD) at the interface reached 6 mm or when it was considered that the number of cycles corresponding to a PSD of 6 mm could be extrapolated.

In the course of the American research program SHRP (Sousa *et al.* 1994) a relatively complicated test device for performing simple shear tests, the so called Superpave shear tester (SST) was developed. Originally the device was not used to evaluate the interlayer shear properties between pavement layers, but to determine permanent deformation and the modulus of asphalt layers.

The SST consisted of shear and axial actuators, load cells and deformation measurement systems, computer control and data acquisition systems, a temperature control and a hydraulic pump. This machine uses closed-loop computer driven control hydraulic pistons connected to vertically and horizontally operating platens. The specimen was normally glued onto aluminum “caps” which were hydraulically clamped to platens inside the temperature control chamber.

Mohammad *et al.* (2002) performed simple direct shear tests on various types of tack coat materials at several spread rates using laboratory fabricated asphalt specimens. A custom made shearing apparatus was designed and fabricated for use in the SST. Specimens were fabricated in the gyratory compactor in two lifts with a tack coat applied prior to compaction of the second lift. The apparatus was mounted inside the SST and the tests were conducted in constant load mode (222.4 N/min).

No normal load was applied to the specimens. The tests were conducted at 25 °C and 55 °C.

As opposed to bond testing using pull-off or torque devices, shear testing is generally performed in the laboratory. In the early 1980s Empa developed a method for shear testing in situ. The shear test with a truck tire was used to test the adhesion between bituminous surface courses and cement concrete layers. Additional to the horizontal shear force a vertical force induced by a single truck tire was applied during the test and the caused deformations were measured (Empa report 1985, not for public use).

In some European countries bond testing was standardised during the 1990s. Although the requirements often stayed below the limits shown in different research projects, standardisation was a first step using shear bond testing on a regular bases in quality control. Research by Raab and Partl (1999; 2008) for example showed that for pavements with stone mastic asphalt (SMA) and asphalt concrete surface courses, a max shear force of 21 kN or 18 kN for the adhesion between the base courses could easily be obtained for 150 mm cores. Nevertheless, Swiss specification only required a max shear force of 15 kN between surface and binder course and 12 kN between a binder and a base course or between two base courses. These values correspond to 1.3 N/mm<sup>2</sup> for the adhesion between surface and base course and 1.1 N/mm<sup>2</sup> between two base courses when using the shear strength the values. In Germany a research project launched by the German Road Authorities in 2001 (Stöckert 2001) and based on approx 500 cores with SMA or AC surface course delivered similar results and proposed the following requirements for the adhesion between the layers:

25 kN for the adhesion surface course/binder course;

20 kN for the adhesion binder course/base course;

16 kN for the adhesion surface course/base course.

In Austria the adhesion testing according to Leutner was conducted on 100 mm specimens and a test temperature of 20 °C ± 1°C. According to the *RVS 8S.04.11: 2004* for SMA and AC surface and the binder course a min shear strength of 0.8 N/mm<sup>2</sup> was required when using a non modified binder and 1.2 N/mm<sup>2</sup> when using a modified binder tack coat. For binder and base courses or two base course layers the requirements were 0.5 N/mm<sup>2</sup> for non modified and 1.0 N/mm<sup>2</sup> for polymer modified tack coats. The shear strength in Austria had to be measured parallel to the direction of the traffic.

In Tables 1 to 3 schematic drawings of the different direct and simple shear devices are presented. Since the shear equipment was often not included in standards and testing specifications, the main test parameters such as specimen dimension (core diameter), deformation rate (test speed), test mode (static, dynamic), normal force, temperature, and others parameters such as the gap width between the shear plates according to special are also given.

### 3. Discussion

As Tables 1 to 3 depict there is a great variety of test devices to test the shear bond of asphalt pavements. The shear tests are inspired by shear testing in soil mechanics and application with or without normal force are used. The application and influence of normal force is one of the issues which have been under debate for quite some time. Many researchers argue that the normal force, representing the wheel load on the road, has to be included in interlayer bond testing. Regarding its influence (e.g. the magnitude of normal force) different opinions and findings are being discussed (Romanoschi, Metcalf 2002; Uzan *et al.* 1978).

Furthermore, when looking at the presentation and interpretation, as well as the comparison of the test results from different shear devices, no uniform opinion is available. Although some common statements such as the dependency of adhesion tests on temperature or deformation rate are not debated among researchers, there are many divergent results regarding the influence of normal stress, tack coat and surface roughness on the adhesion properties (Raab, Partl 2004; Romanoschi, Metcalf 2002; Uzan *et al.* 1978; Ziari, Khabiri 2007).

Especially for quality assurance, standards and testing specification only require the interlayer bond values in form of forces since test specifications prescribe specific test specimen diameters. This method is easy for comparison of specimens of equal size, but has a disadvantage for the comparison with other results.

Another distinction between different test devices is their workability and the simplicity of performing a test. Here, devices using clamping mechanisms are preferable over devices where the test specimens have to be glued into moulds. The more time is needed for specimen preparation, and the more cumbersome a test set up becomes (e.g. the MCS device), the greater the influence of unknown variables on the test results and test devices are not likely to be used for daily quality assurance. Looking at the guillotine devices, the different clamping mechanisms play an important role for the workability but they are also important for a defined pressure with which specimens are held during the test (e.g. as in the Empa test device). Furthermore, devices using prismatic specimens are more practical especially for quality assurance since field specimens are mostly drilled cores and even a lot of laboratory specimens such as Marshall and gyratory specimens are prismatic. Some devices are flexible in a way that they allow for the testing of either prismatic or rectangular specimens (e.g. Empa test device, ASTRA test device). Another advantage of the guillotine (Leutner) type devices is that they are very flexible since they can be installed in a common universal testing machine requiring no special test set ups and constructions.

That the comparison of different test devices as well as their results and outcome becomes a more and more important issue shows the inter-laboratory test program initiated by RILEM. Here, research and materials testing institutions from Europe and North America were asked to perform shear tests on pre-selected and defined mate-

rial under certain test conditions using their specific shear test equipment (Piber *et al.* 2009). First investigations show that a comparison of results in case of the Leutner device (or some of its modified versions) leads to similar findings and tests using 100 mm or 150 mm specimens provide similar results.

### 4. Conclusions

The paper presents an extended overview on the existing test shear test devices and gives detailed information on the functioning mechanisms (device figures) and test specifications.

Looking at the different publications and devices the following statements and conclusions can be drawn.

Shear testing seems to be a good and effective method for testing the interlayer bond of asphalt pavements.

In many publications some of these test methods and devices are described by presenting photographs and sketches. Often photographs show the functioning of the devices only insufficiently and detailed information regarding the test devices (e.g. gap width) and test conditions (e.g. loading function, normal force) are difficult to retrieve. Therefore, detailed drawings showing the mechanism of a device as depicted in this paper are preferable.

For the construction of test devices it is important that the test set up is not complicated and the installation of test specimens is simple. Clamping mechanisms are often preferable over set ups where specimens have to be glued or fixed into special moulds. When clamping the specimen, care has to be taken that this procedure does not damage the specimen and does not influence the test results. Therefore, it is important that a defined pressure is used and that the specimen is not tilted during the test.

The gap between upper and lower part of the shear moulds has to be small enough not to induce a bending moment. The device itself has to be sufficiently stiff to enable the occurring forces to be accommodated.

Although shear failure normally occurs in warm climate, moderate test temperatures (around 20 °C) seem to be preferable, as compared to testing at hot temperature the danger of damaging the specimen during testing is smaller.

For the comparison of different test devices, it is important that test parameters such as normal force and deformation rate are comparable. The application of normal forces has an influence on test results and more research is necessary to clearly work out in which way.

Regarding the results from interlayer shear bond testing it is important to compare the outcome of different devices and methods in a detailed way. The above mentioned Rilem interlaboratory test provides a first step in this direction, but here definitely more research is needed.

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