Temperature dependency of interlayer shear testing

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Abstract

For many years the Leutner test has been used to determine the interlayer shear strength. This test is conducted at ambient temperature, normally 20°C. Although it is known that the shear behaviour is highly temperature dependent, the reason for testing at ambient temperature is manifold. At elevated temperatures (30°C to 40°C) the shear strength is critical, but also testing and specimens handling becomes more difficult and may lead to unintentional errors in measurement. At low temperatures shear strength is expected to increase, which on one hand is less critical and on the other hand may exceed the capacity of the testing machine. In the course of an investigation conducted to characterize the interlayer behaviour of double layered asphalt pavement specimens co-axial (CAST) and Leutner shear tests were used to determine the complex modulus, the shear stiffness and the shear strength. It was found that from both CAST and shear test results, the ranking of stiffness in double layered asphalt specimens was different at different test temperatures and frequencies. Based on these shear test results it was concluded that the experimental investigation for interlayer shear behaviour should be performed at different temperatures. In order to check this important finding, a new series of shear tests was conducted at temperatures of +20°C, 0C° and -20°C. The results confirmed that the ranking of shear force (stress) and shear stiffness for different inter-layers can change when tested at -20°C instead of +20°C and therefore shear testing at one temperature (20°C as requested for Leutner shear testing) might not be sufficient. Furthermore, interlayer bond defects or weaknesses seem to show better when testing is performed at a very low temperature of -20°C.

1. Introduction

Asphalt pavements are multi-layered composite systems. Hence, mechanical behaviour depends on both the individual material properties of each layer and the properties of the interfaces that define the interaction between each layer. This interaction depends on a large variety of parameters as outlined by Raab and Partl (Raab and Partl, 1999) and is therefore often considered the weak spot of a pavement structure where horizontal water infiltration, propagation of cracks and debonding can easily occur.

For many years the Leutner test (Leutner, 1979) has been used to determine the interlayer shear strength between asphalt layers. This test is normally conducted at an ambient temperature between 20°C to 25°C. The reason for testing at ambient temperature is manifold. At elevated temperatures (30°C to 40°C) the shear strength is critical, but testing and specimen handling becomes more difficult and may lead to measurement errors. Furthermore, at elevated temperatures, the difference in shear strength between the different asphalt types becomes small and less distinguishable for different asphalt mixes especially, when the binder gradually looses its binding properties.

Reduced distinguishability between different mixes can also occur at temperatures below 0°C when the interlocking effect at low temperature is supposed to play a minor role due to increased stiffness and bonding properties of the asphalt binder. At low temperatures shear strength is also expected to increase, which on the one hand is less critical and on the other hand, may exceed the capacity of the testing machine.

In the course of an investigation to characterize the interlayer behaviour of double layered asphalt pavement specimens where co-axial shear tests (CAST) and Leutner shear tests (LPDS) were used to determine complex modulus, shear stiffness and shear strength it was found that from both CAST and LPDS results, the ranking of overall stiffness in double layered asphalt specimens was different at different test temperatures and frequencies (Sokolov et al. 2005, Kim et al. 2009).

Based on the LPDS results it was concluded that interlayer shear behaviour should be investigated at different temperatures. In order to confirm this important finding, a new series of shear tests was conducted at temperatures of +20°C, 0C° and -20°C. This existing investigation presents both the shear test results from the earlier investigation and the results from the new series of shear tests conducted at temperatures of +20°C, 0C° and -20°C.

2. Materials

In both cases, specimens were cored from two slabs of a four-layered Swiss motorway pavement. The locations where the slabs had been taken were only few kilometres apart and were of the same design. The pavement consisted of a stone mastic surface course SMA 11 with a nominal maximum aggregate size of 11mm, an asphalt concrete binder course AC 22, and an asphalt concrete base course AC 32 with nominal maximum aggregate sizes of 22 mm and 32 mm respectively, as per to the Swiss Standard SN 640420. The subgrade material consisted of asphalt concrete AC S 22 with a nominal maximum aggregate size of 22 mm. The pavement of slab 1 and 2 was constructed in 1998. Slab 1 was extracted in 2006, while slab 2 had already been removed prior to trafficking in 1998. The daily traffic volume on the motorway increased from about 52’000 in 2000 to 60’000 in 2005, while the percentage of heavy vehicles in 2005 was given with 8.6%.

Table 1 Pavement design (values of slab 2)

Layers	Mixture type	Binder grade [pen]	Binder content [mass-%]	Air void [vol-%]	Thickness [mm]
Layer 1	SMA 11	55/70 + Trinidad lake asphalt+fibres	5.8	3.2	40
Layer 2	AC 22	Mixelf 10/20	4.8	4.0	70
Layer 3	AC 32	Mixelf 10/20	4.8	4.3	120
Layer 4	AC S 22	80/100	4.4	6.5	95

In the case of slab 1 LPDS interlayer shear tests at 20°C were conducted in 2006. Both the inlayer LPDS shear testing and LPDS interlayer shear testing at -20°C were carried out in 2009 using cores from the same pavement slab. These had both been stored under ambient room temperature condition since 2006. All testing on slab 2 was conducted in 2009.

Further details of the mixtures are given in Table 1. Note that Layer 1 contained natural asphalt and layers 2 and 3 were composed of SBS polymer modified binder. In the following, the interfaces between Layer 1, Layer 2, Layer 3, and Layer 4 will be denoted by Interlayer 12, Interlayer 23 and Interlayer 34. Binder and air void content results, given in Table 1, represent results of an investigation into slab 2 carried out in 1998 immediately after construction. The values in the table can be taken as representative for all other slabs.

3. Shear Testing

The shear testing was conducted with the Leutner shear device or the Layer-Parallel Direct Shear (LPDS) test device (Partl and Raab 1999) which is an Empa-modified version of equipment originally developed in Germany by Leutner (Leutner, 1979). In both devices the shear load is induced to the core head with a deformation rate of 50 mm/min thus, producing fracture within the pre-defined shear plane.

From the shear test the shear force, F, as a function of shear deformation, w, on top of the specimen can be used to determine the maximum shear force, $F_{max,}$ and to calculate the nominal average shear stress τ_{LPDS} in the cross section of a cylindrical specimen with diameter d from:

$$\tau = \frac{F}{A} = \frac{4F}{d^2 \pi} \qquad (1)$$

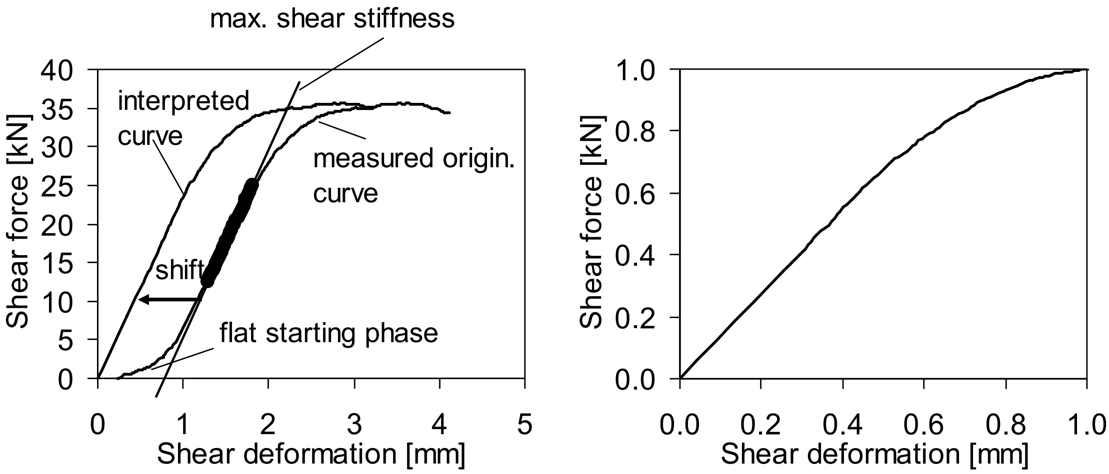
where, F = maximal force, A = nominal cross section area, and d = specimen diameter.

Since the specimen diameter is the same for all LPDS testing, shear strength is often not expressed by the nominal maximal shear stress, but by the maximal shear force. In addition to the shear force the maximum slope from the diagram of shear force, F, versus shear deformation, w, can be used to define an indicator for stiffness, S_{LPDS}, (further called “stiffness“) as follows:

$$S_{LPDS} = \frac{\Delta F}{\Delta w} \qquad (2)$$

where, ΔF = differential force and Δw = differential deformation.

From the single curves of shear force versus shear deformation, the mean values with standard deviation of the maximum shear stress and shear stiffness as well as the mean curves of shear force (or shear stress) versus deformation were determined. To obtain the mean curves, the procedure was the following: In a first step, the flat starting phase of the measured original curves was replaced by the tangent defined as the calculated maximum shear stiffness (Figure 1(a)). After that, the whole curve was horizontally shifted into the origin of the coordinate system. This was done for all single curves. In a second step, the single curves were normalized as shown in Figure 1(b) (maximum shear force value and corresponding shear deformation were defined as “1”) and all curves were summed up and divided by the number of curves (average). In a last step, the mean curve was determined by multiplying the normalized mean curve with the mean maximum shear force respectively the mean maximum shear stress and the associated mean deformation.



a) *b)*

Figure 1. Method to determine mean shear force – shear deformation curves.

4. Shear Test Results

Table 2 shows all results of in-layer and interlayer shear testing for slabs 1 and 2 at different temperatures. The table shows the mean values from 4 to 8 (normally 6) repetitions and the standard deviation is given in brackets.

Table 2 Pavement design (values of slab 2)

Layer	Temp. [°C]	Shear force [kN] traffic	Shear force [kN] no traffic	Shear stress [MPa] traffic	Shear stress [MPa] no traffic	Shear stiffness [kN/mm] traffic	Shear stiffness [kN/mm] no traffic
		slab 1	slab 2	slab 1	slab 2	slab 1	slab 2
Layer 1	20	30.7 (3.6)	-	1.8 (0.2)	-	17.5 (2.9)	-
Layer 2	20	85.7 (7.2)	-	4.9 (0.4)	-	45.0 (6.3)	-
Layer 3	20	89.6 (7.3)	-	5.1 (0.4)	-	64.0 (7.2)	-
Layer 4	20	40.6 (6.7)	-	2.3 (0.4)	-	30.3 (8.0)	-
Interlayer 12	0	42.0 (3.2)	34.1 (6.3)	2.4 (0.2)	1.9 (0.4)	30.6 (6.3)	20.2 (9.6)
	20	-	75.1 (6.1)	-	4.3 (0.3)	-	62.6 (2.8)
	-20	69.0 (9.5)	70.6 (15)	3.9 (0.5)	4.0 (0.9)	92.0 (10)	71.6(12.7)
Interlayer 23	0	29.5 (5.3)	27.4 (9.6)	1.7 (0.3)	1.5 (0.5)	42.0 (3.2)	31.7 (9.6)
	20	-	30.3 (6.6)	-	1.7 (0.4)	-	52.1 (9.4)
	-20	-	17.7 (7.2)	-	1.0 (0.4)	-	40.3(10.4)
Interlayer 34	0	36.5 (1.0)	14.9 (2.9)	2.1 (0.1)	0.8 (0.2)	39.1 (2.5)	20.8 (5.2)
	20	-	21.6 (5.5)	-	1.2 (0.3)	-	39.6 (4.1)
	-20	27.0 (7.4)	17.2 (5.2)	1.5 (0.3)	1.0 (0.3)	51.0(12.8)	35.2 (9.4)

5. In layer and interlayer behaviour

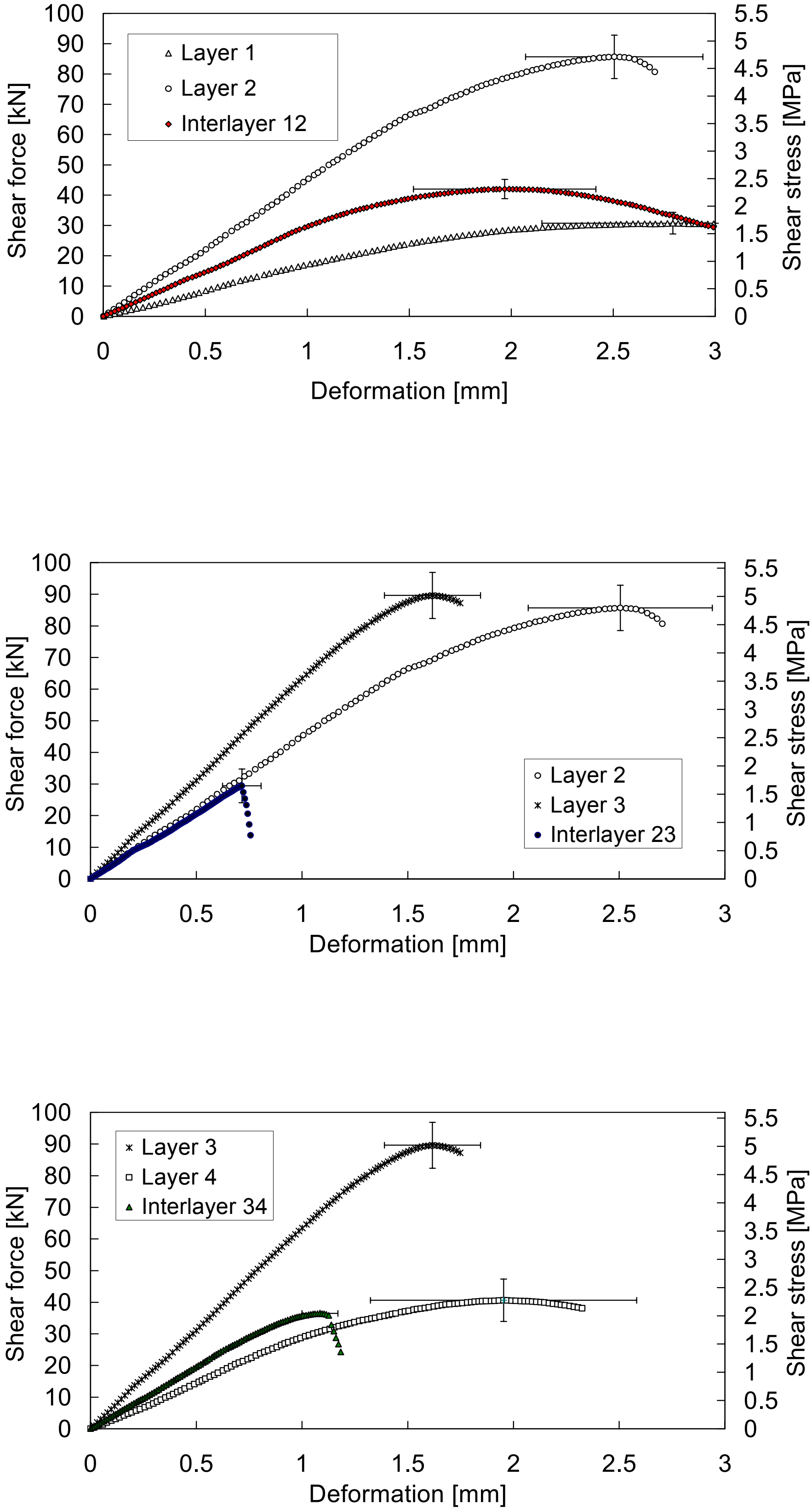


Figure 2. Comparison of inlayer and interlayer shear test results for slab 1 at 20°C.

Since in-layer testing was only conducted for slab 1 (after trafficking), Figure 2 depicts the comparison of in-layer and interlayer shear testing for this slab at a temperature of 20°C.

Comparing mean inlayer and interlayer shear results for Layer 1 shows that both the maximum shear force of 42 kN (or stress of 2.4 MPa) and the shear stiffness of 30.6 kN/mm are higher in the interface than in the material of the first layer itself (maximum shear force of 30.7 kN, stress of 1.8 MPa and stiffness of 17.5 kN/mm). A similar observation was already reported for surface course materials in an earlier investigation (Partl and Raab 1999).

The shear test of the Layer 2 produced a maximum shear force of 85.7 kN (or shear stress of 4.9 MPa) and a stiffness of 45 kN/mm. These values are significantly higher than those of Layer 1 and of Interlayer 12. Layer 3 has the highest shear strength and stiffness (maximum shear force of 89.6 kN, stress of 5.1 MPa, and stiffness of 64 kN/mm), while bottom Layer 3, reveals the lowest inlayer behaviour of the two base courses, with mean values of 40.6 kN for the maximum shear force, 2.3 MPa for stress, and 30 N/mm for stiffness.

For the Interlayer 23, with a maximum shear stress of 1.7 MPa and a shear stiffness of 42 kN/mm both being similar to the second layer, a conclusion is difficult to draw since the interface experienced severe bonding problems. When compared to Interlayer 23, Interlayer 34 achieves a slightly higher maximum shear stress of 2.1 MPa and a shear stiffness of 39 kN/mm which is between the stiffness of Layers 3 and 4.

Generally, it was observed that the in-layer curves can normally be found between the interlayer curves, often tending to be closer to the one with the lower shear stiffness.

6. Temperature dependency

Figure 3 depicts the interlayer shear forces of slabs 1 and 2 at temperatures of +20°C, 0°C and -20°C, while Figure 4 shows the shear stiffness results.

Since, in the first investigation (slab 1), interlayer 23 was found to have broken prior to testing interlayer 12 at -20°C, slab 2 alternatively tested Interlayer 23 first.

6.1 Shear force

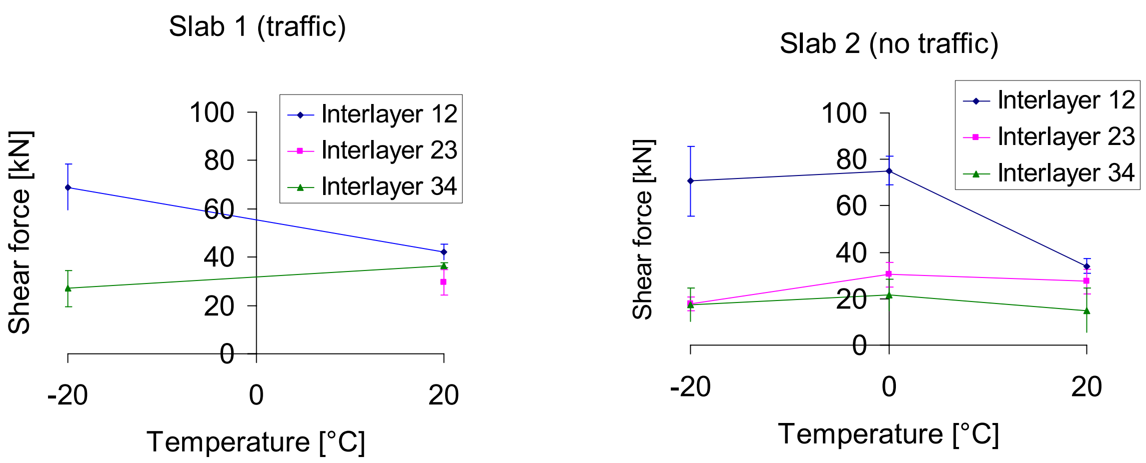


Figure 3. Shear forces of slabs 1 and 2 at temperatures of 20°C, 0°C and -20°C.

6.2 Shear stiffness

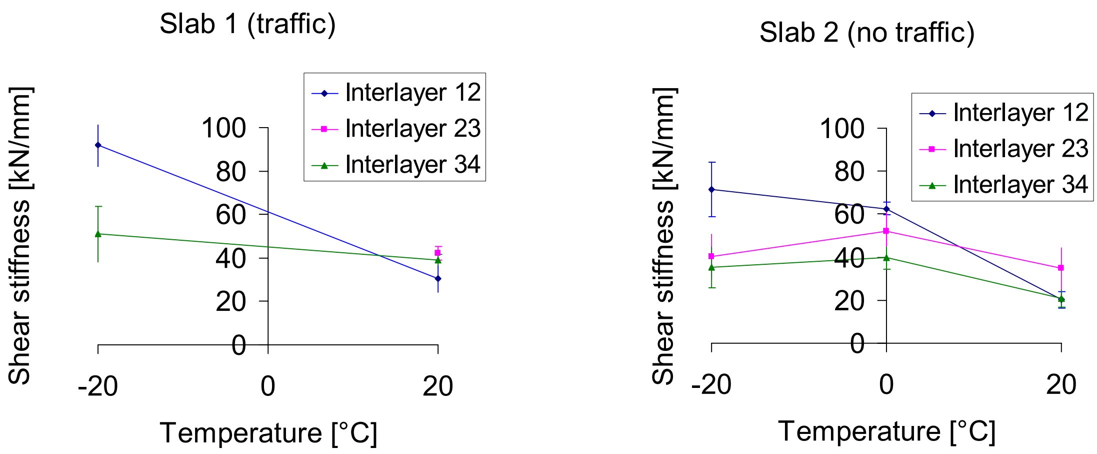


Figure 4. Shear stiffness of slabs 1 and 2 at temperatures of 20°C, 0°C and -20°C.

As expected, testing at lower temperature (0°C and -20 °C) leads to a more brittle behaviour generally resulting in higher shear stiffness.

When the results for slab 2 are viewed, whereby testing was conducted at three different temperatures, shear forces and in most cases shear stiffness are highest at 0°C. Whereas, -20°C seems to be a more critical temperature.

While for Interlayer 12 (slabs 1 and 2) the test results at -20°C compared to the results at +20°C lead to a significantly higher maximum shear force and shear stiffness, it is interesting to note that the ranking of shear test results for interlayer 34 (slab 1) and interlayer 23 (slab 2) are the opposite (i.e. lower shear forces at -20°C). It seems that interlayer bond deficiencies or defects as observed with Interlayer 23 are made more obvious when testing is performed at very low temperature, i.e. -20°C.

That the shear force and stiffness results for slab 1 are generally higher than the ones for slab 2 (although the asphalt design and material is identical) can be contributed to the fact that the slab 1 had been taken 8 years after construction and trafficking (2006). This confirms the findings of other investigations by Raab and Partl which showed there is an increase of shear force and stiffness in case of intact and well designed pavements after trafficking (Raab and Partl, 2008, Raab and Partl 2009).

When comparing the temperature ranking for shear force and shear stiffness it is important to note that it is completely different.

7. Conclusions

From the investigation described in this chapter the following conclusions can be drawn:

It is a well-known fact that shear testing is highly temperature dependent, in which testing at high temperature leads to lower shear force and stiffness values whereas lower temperatures generally result in higher values.

Shear force and in most cases shear stiffness values are highest when testing is performed at a temperature of 0°C.

The ranking of shear force (stress) and shear stiffness for different interlayers can change when tested at -20°C instead of +20°C and therefore shear testing at one temperature (20°C as requested for Leutner shear testing) might not be sufficient.

Interlayer bond defects or weaknesses seem to appear more obvious when testing is performed at very low temperature of -20°C.

As observed in earlier investigations, the in-layer stiffness of a surface course layer is lower than the one of the first interlayer (Interlayer between surface and base layer). Often, in-layer curves can be found between the interlayer curves, often tending to be closer to the one with lower shear stiffness.

Traffic, not exceeding the design limits, leads to higher shear forces for a pavement compared to untrafficked one. Hence, the finding that the interlayer bond properties of intact and well designed asphalt pavements such as shear force (stress) and stiffness increase over time could be supported by the results of the study.

8. References

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