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RILEM interlaboratory test on interlayer bonding of asphalt pavements

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RILEM TC 206 ATB TG 4

ABSTRACT: The RILEM TG 4 organized an interlaboratory test in order to compare the different test procedures to assess the interlayer bonding properties of asphalt pavement. The pavement was composed of two layers. Three different interface conditions were chosen. The first pavement was laid without interface treatment and the others with two different types of emulsion. 14 laboratories from 11 countries participated in this study and carried out shear or torque tests on 1400 cores. The maximum shear or torque load and the corresponding displacement were measured and the shear or torque stress was calculated as a function of the following parameters: diameter, test temperature, test speed, stress applied normal to the interface and age of the specimen. This paper presents the results of this study in terms of precision and correlations regarding the parameters.

1 INTRODUCTION

Interlayer shear resistance has recently attracted increasing interest worldwide due to the fact of steadily increasing requirements on pavement performance properties in terms of bearing capacity and durability as well as new innovative developments regarding pavement materials and construction. However, test methods available for assessing interlayer shear resistance and their reliability are under much discussion. In particular interpretation of laboratory data in connection with data from real pavements are subject to uncertainties. So far, no general consensus exists regarding test methods, assessment criteria and international standardization. Hence, RILEM TC 206 ATB TG 4 organized an interlaboratory test on interlayer bonding considering three different interface conditions of asphalt concrete pavements. The test focused on the comparison of shear test procedures, test conditions, specimen geometries and devices that allow determining interlayer shear resistance in asphalt concrete.

The aim of this interlaboratory test was twofold:

Determine the repeatability and reproducibility of interlayer shear tests proposed by the majority of the different participants.

Determine correlations between different test procedures and evaluate the influence of different test conditions.

2 TRIAL SECTION

Samples were taken from a newly laid asphalt pavement near Ancona (Italy) in summer 2005, managed by the Università Politecnica delle Marche.

The trial section was 3.5 m wide and about 20 m long and composed of two layers. The lower layer had a thickness of 70 mm and consisted of an asphalt mixture type AC 16 base 70/100 (EN 13108-1). The upper layer was 30 mm thick and produced with an asphalt mixture type AC 11 surf 70/100 (EN 13108-1).

Three different interface conditions were chosen.

- Pavement 1: without treatment (not hot on hot!)
- Pavement 2: pre-coated with a polymer modified emulsion
- Pavement 3: pre-coated with a conventional cationic emulsion.

The two courses were laid by an asphalt finisher and compacted by a roller. The production of the three pavements was done consecutively in one single construction process. The application rate was about 150 g/m² of residual bitumen for both Pavement 2 and Pavement 3. Asphalt cores were taken following a well defined coring pattern with a clear documentation of the position of the cores (Figure 1). Each core was marked by a special code defining its location in the trial section. The cores had a nominal diameter of 100 mm or 150 mm. The direction of laying was marked and identical to the direction of testing.

3 TEST PROGRAM

3.1 *Participating laboratories*

The 14 laboratories participating on a voluntary basis are listed as follows:

- Amt der Kärntner Landesregierung—Bautechnik, Klagenfurt, Austria
- EMPA Dübendorf, Switzerland
- Institut für Straßenbau und Straßenerhaltung der TU Wien, Vienna, Austria
- Institut für Straßenwesen der TU Braunschweig, Braunschweig, Germany
- Laboratoire 3MsGC, Centre Universitaire de Génie Civil, Egletons, France
- National Centre for Asphalt Technology, Auburn, AL, U.S.A
- National Cheng Kung University, Department of Civil Engineering, Tainan, Taiwan
- NCPE University of Nottingham, Nottingham, UK
- Nynas AB, Nynäshamn, Sweden
- Nynas UK AB, South Wirral, UK
- Road and Bridge Research Institute, Jagiellonska, Poland
- Transport Research Centre of CEDEX, Madrid, Spain
- Università Politecnica delle Marche, Ancona, Italy
- University of California Pavement Research Centre, Richmond, CA, U.S.A.

Figure 1. Trial section after taking 100 and 150 mm cores from Pavement 1.

3.2 *Test program*

The laboratories carried out shear or torque tests on a total of about 1400 cores. At each test condition 7 specimens were tested. The test conditions varied in terms of diameter, test temperature, test speed, stress applied normal to the interface and age of the samples. The maximum shear load or torque moment and the corresponding displacements were measured and the nominal maximum shear or torque shear stress were calculated. The test program is given in Table 1. In this paper only the results of the static shear test are reported.

3.3 *Shear test devices*

The shear tests were performed either in pure direct shear configuration (Figure 2) or direct shear configuration with normal stress (Figure 3).

4 PRECISION OF THE SHEAR TEST

The evaluation of the precision will give information about the quality of the data within each laboratory (repeatability standard deviation s_r) and among different laboratories (reproducibility standard deviation s_R). The statistical analysis was done according to ISO 5725-2—Accuracy (trueness and precision) of measurement methods and results—Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method.

The results of the shear test were analyzed if more than three laboratories tested "identical" specimen under the same test conditions. In this part of the research program 539 specimens were tested without normal stress and evaluated.

- Diameter D = 100 mm, test speed v = 2,5 mm/min, temperatures T = 10°C, 20°C, 30°C,
- Diameter D = 100 mm, test speed v = 50 mm/min, temperature T = 20°C,
- Diameter D = 150 mm, test speed v = 50 mm/min, temperature T = 20°C, 30°C.

The study showed that the values s_r (repeatability standard deviation) and s_R (reproducibility standard deviation) are closely related to the mean values of the maximum nominal shear stress "τ" regardless of specimen diameter, test speed and temperature. Precision within

Table 1. Test Program; "x" in matrix denote test conditions; (v: test speed, σ_n: normal stress).

Unidirectional monotonic static shear test										
Diameter (mm)		150					100			
Temperature (°C)		10	20	25	30	40	10	20	30	40
σ_n (MPa)	v:									
	1.27 (mm/min)				x					
	12.7 (mm/min)				x					
0	2.5 (mm/min)				x		x	x	x	
	25 (mm/min)				x					
	50 (mm/min)	x	x	x	x	x	x	x	x	
	200 (mm/min)	x	x		x					
0.049	2.5 (mm/min)			x	x	x				
0.2	2.5 (mm/min)						x	x	x	
0.483	2.5 (mm/min)								x	x
0.6	2.5 (mm/min)						x	x	x	
Monotonic static torque test										
0	180°/min	x	x		x		x	x	x	
	600 N/min						x	x	x	
Unidirectional cyclic fatigue shear test										
	10 Hz		x							

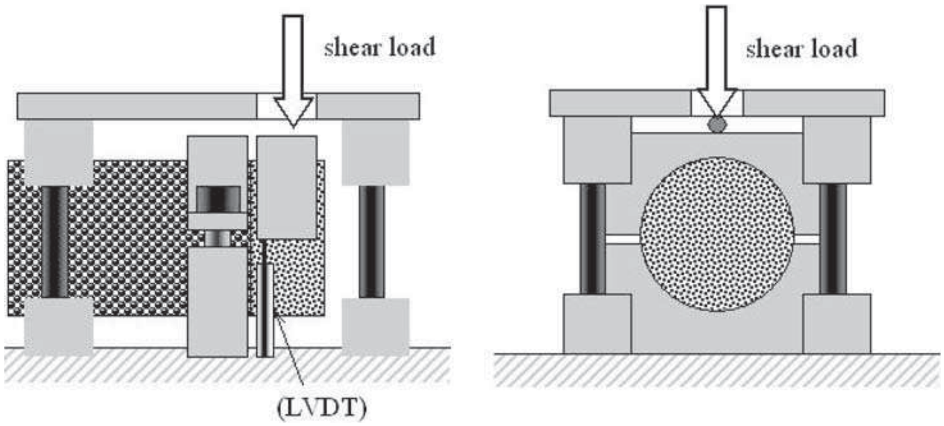

Figure 2. Pure direct shear device (Leutner).

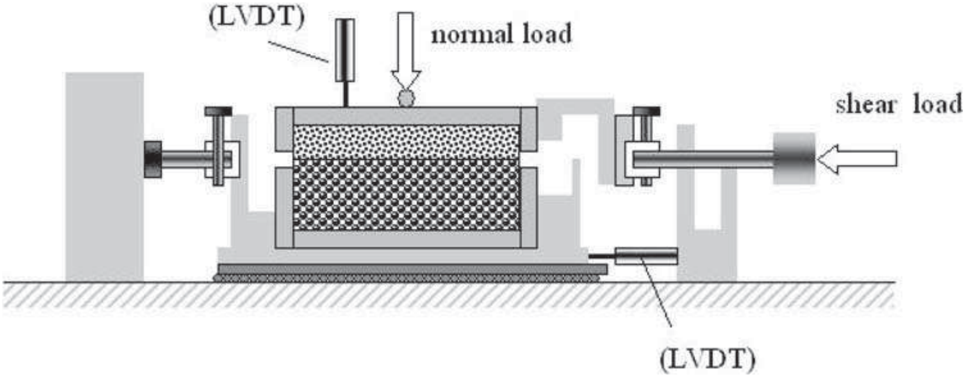

Figure 3. Direct shear device with normal load (ASTRA).

one laboratory is based on testing the “same” sample by the same technician with the same device. Since shear tests are destructive tests this condition was not fulfilled. Therefore the results of the shear test had to be checked with respect to their homogeneity within the trial section. Finally it was found that the precision of the shear test in case of absolutely homogeneous area of the trial section is:

– Repeatability standard deviation: $s_r = 0.05\,\bar{\tau}$ (MPa)
– Reproducibility standard deviation: $s_R = 0.12\,\bar{\tau}$ (MPa)

5 INFLUENCE OF TEST PARAMETERS ON SHEAR TEST RESULTS

5.1 *Influence of specimen diameter*

For the determination of the influence of specimen diameter nine pairs of values were available. The mean shear stress values for all three pavements tested at a speed of 50 mm/min and temperatures of 10°C, 20°C and 30°C were evaluated based on 616 cores. The evaluation showed that all shear stress values for all temperatures tested with cores of 150 mm diameter were lower than the results of the test carried out with 100 mm asphalt cores. The correlation is given by Equation 1 and the corresponding coefficients are listed in table 2.

$$\tau_{D=100\ \mathrm{mm}} = a \cdot \tau_{D=150\ \mathrm{mm}} \qquad (1)$$

Table 2. Coefficient a and R^2 of the different pavements.

Pavement	a	R^2
1	1.07	0.86
2	1.13	0.99
3	1.16	0.94

It appears that the factor "a" depends on the interface condition. Moreover as expected the presence of emulsion mitigates the scatter of shear stress at the interface giving higher R^2 values for pavement 2 and 3. The linear regression for all samples has a coefficient of $R^2 = 0.970$. It was found that shear stress of 100 mm cores is about 14% higher than shear stress of 150 mm cores.

5.2 *Influence of the test speed*

Totally 77 cores were tested. The test speed used by the different laboratories for the shear tests ranged from 1.27 mm/min to 200 mm/min. In Figure 4, the shear stress results obtained for Pavement 3 considering five different test speeds are presented.

Figure 4 indicates in the speed range indicated a strong power function type of relationship with a high regression coefficient ($R^2 = 0.99$).

The other data were evaluated in a similar way and lead to the general equation for all temperatures and pavements (D = 150 mm).

$$\tau = 0.41 \cdot v^{0.22} \tag{2}$$

Again, the regression coefficient ($R^2 = 0.99$) is very high. Note that the exponent of the power function slightly changed as compared to Figure 4. Hence, if one shear stress value and its test speed are known shear stress can be calculated by Equation 3 for whatever test speed as follows.

$$\tau_{vx} = \tau_{v1} \cdot \left(\frac{v_x}{v_1}\right)^{0.22} \tag{3}$$

where:

- τ_{v1} shear stress at test speed 1
- v_1 test speed 1
- τ_{vx} shear stress at test speed x
- v_x test speed x

5.3 *The influence of normal stress*

In order to study the influence of nominal normal stress on the maximum shear stress, the results from one laboratory were considered. The results obtained for the three pavements and for three temperatures (10, 20 and 30°C) were analysed, for a total of 63 specimens (D = 100 mm, v = 2.5 mm/min).

Figure 5 allows the determination of two important contributions to the maximum shear stress: the cohesion and the friction. The cohesion is the value of τ_{max} when the normal load is not applied. Therefore the cohesion is represented by the x axis. The friction is given by the intercept of the straight lines in Figure 5. Further evaluations of the parameters of regression lines in Figure 5 show that these parameters were linearly dependent on the normal stress and lead to the Equation 4 as functions of a general value of σ_n.

$$\tau_{\sigma n} = (1 + 0.38 \cdot \sigma_n) \cdot \tau_{\sigma 0} + (0.74 \cdot \sigma_n) \tag{4}$$

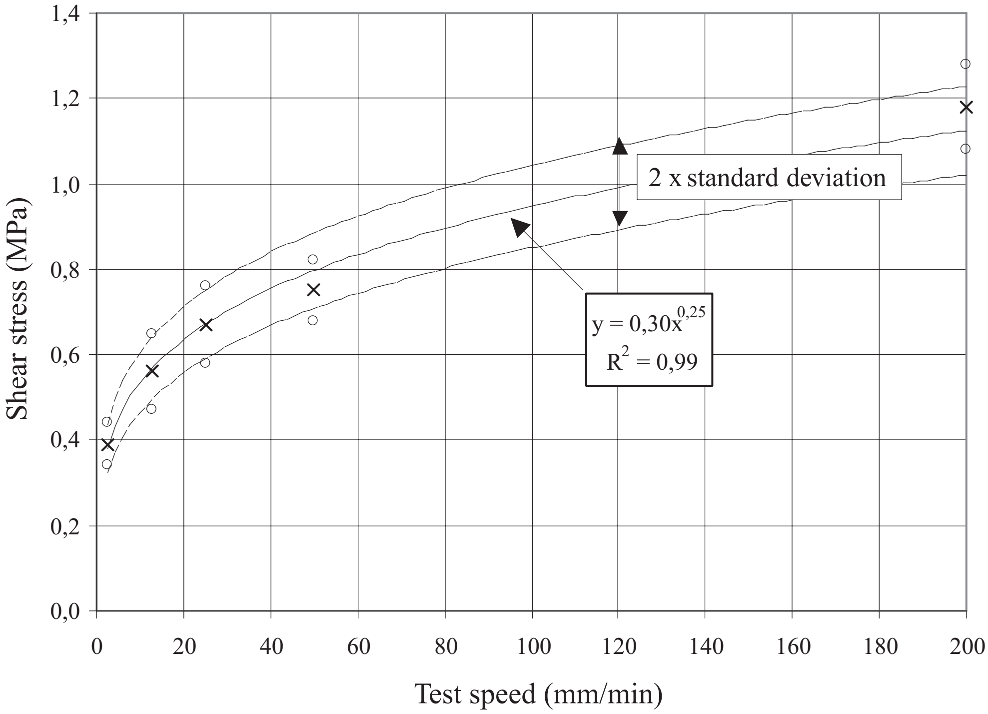

Figure 4. Correlation between test speeds and shear stress at 30°C and D = 150 mm for Pavement 3.

where:

$\tau_{\sigma n}$ shear stress with normal stress σ_n (MPa)
$\tau_{\sigma 0}$ shear stress without normal stress (MPa)
σ_n normal stress (MPa)

5.4 *Influence of the temperature*

In this investigation all laboratories carried out the tests at various temperatures. One laboratory used five temperatures (10°C, 20°C, 25°C, 30°C and 40°C). As an example the results of Pavement 2 are shown for $D = 150$ mm and $v = 50$ mm/min in Figure 6.

A relation between shear stress and temperatures was found as follows.

$$\tau_{T_x} = 10^{aT_x + b} \tag{5}$$

Table 3 presents the corresponding regression coefficient.

From these tests it appears that all pavements follow the same temperature dependency. The mean value of coefficient "a" is –0.023 (± 0.004).

The following figure 5 is an example for $D = 100$ mm and $v = 50$ mm/min and was produced by using these coefficients.

5.5 *Influence of the sample age*

The influence of the sample age in the absence of traffic was checked for Pavement 2. Tests were carried out by two laboratories. The results are shown in table 4.

The evaluations showed an increase of the shear stress. The fact that both laboratories found an increase of shear stress (up to 27%) shows the influence of sample age. However the amount of increase was different which is partly due to the fact that the testing conditions were not identical.

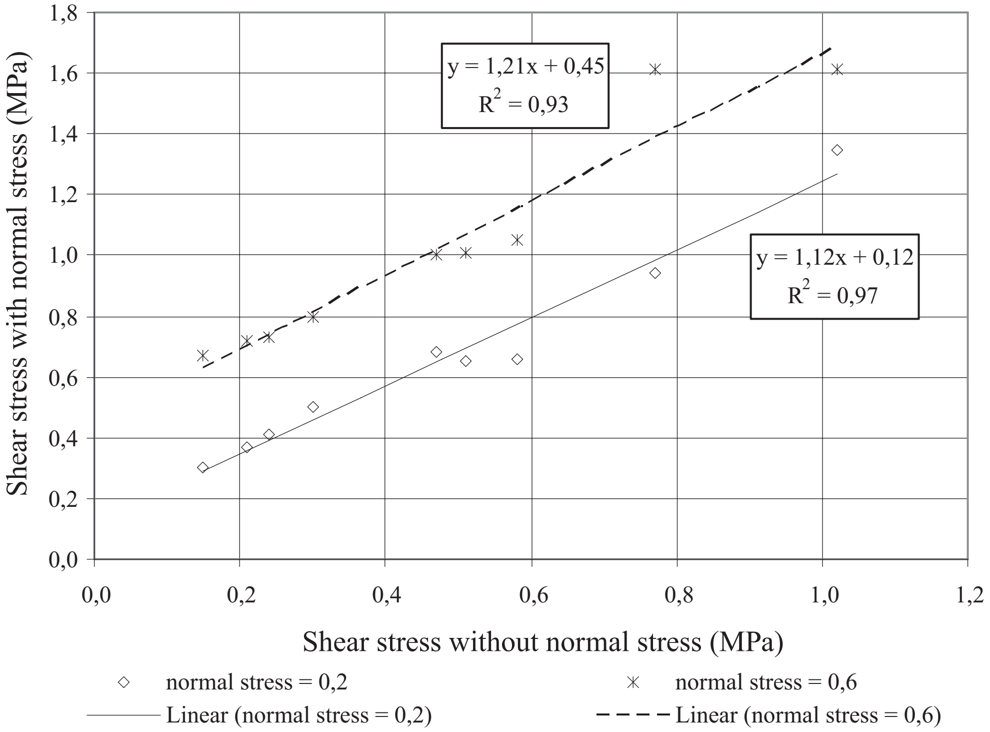

Figure 5. Correlation between shear stress with and without normal stress applied.

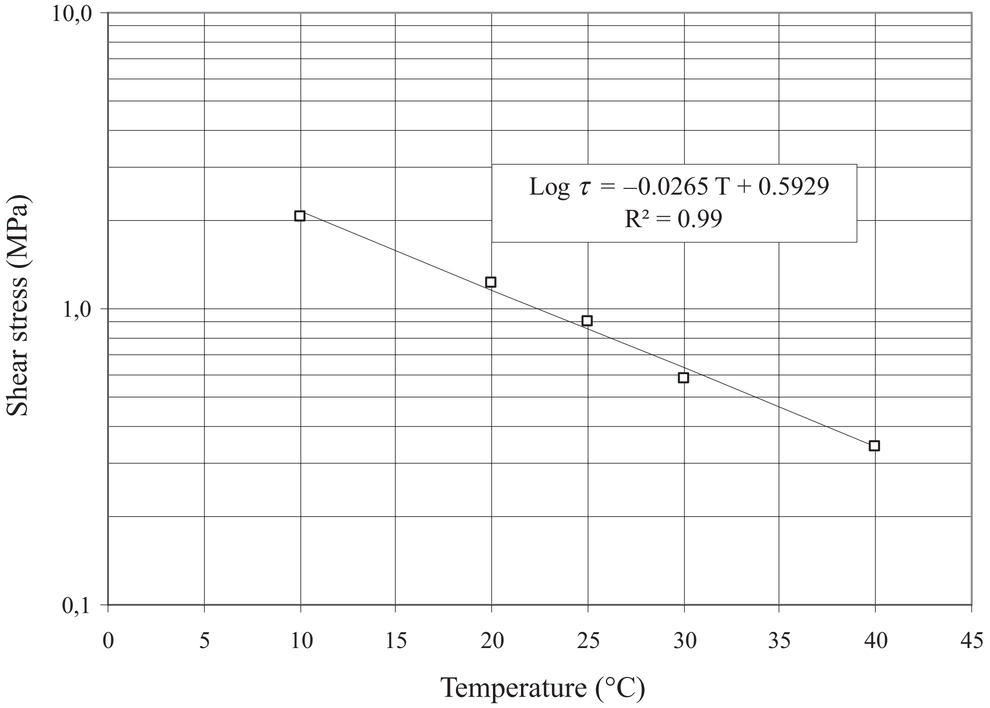

Figure 6. Correlation between shear stress without normal stress and temperatures for Pavement 2 D = 150 mm, v = 50 mm/min.

Table 3. Coefficient a and b for all pavements according to Equation 5.

		Pavement 1			Pavement 2			Pavement 3		
D	v	a	b	R^2	a	b	R^2	a	b	R^2
mm	mm/min	Shear test without normal stress								
100	2.5	–0.021	–0.013	1.00	–0.026	0.308	0.99	–0.023	0.334	0.99
100	50	–0.016	0.211	0.92	–0.025	0.612	1,00	–0.020	0.611	0.97
150	50	–0.026	0.369	0.94	–0.026	0.586	1.00	–0.026	0.638	0.99

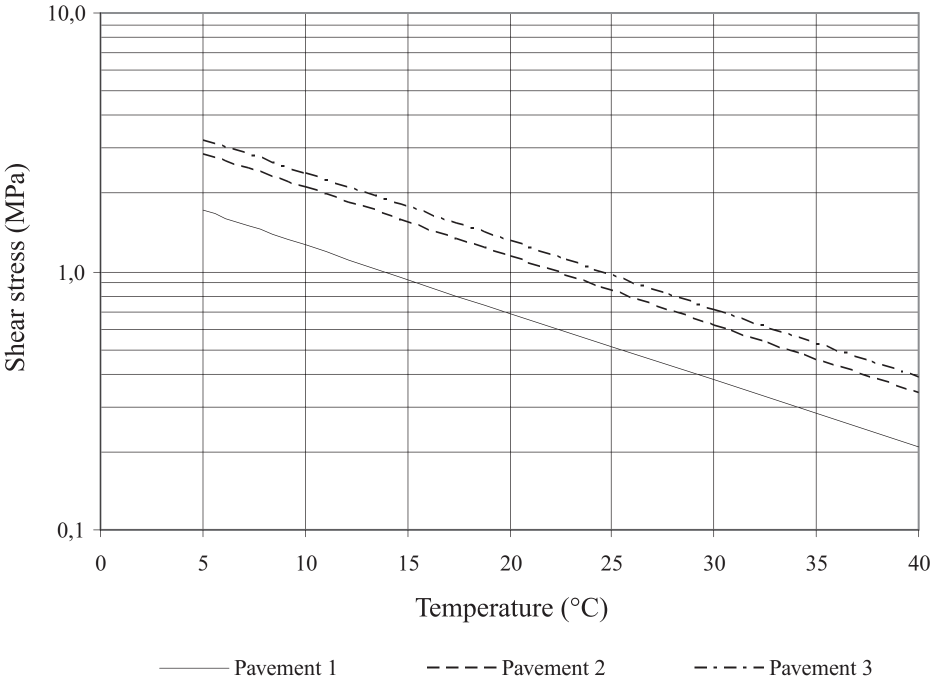

Figure 7. Shear test D = 150 mm, v = 50 mm/min.

6 CONCLUSION

This RILEM interlaboratory test program compares test methods for the assessment of interlayer bonding of asphalt pavements. The conclusions from this investigation can be summarized as follows.

- Generally good agreement exists between different unidirectional monotonic static shear tests.
- The reached precision of the different shear tests is satisfactory; it was found that the precision of the shear test in case of absolutely homogeneous area of the trial section is:
- Repeatability standard deviation: $s_r = 0.05\,\bar{\tau}$ (MPa)
- Reproducibility standard deviation: $s_R = 0.12\,\bar{\tau}$ (MPa)
- The influence of the temperature, the size of the specimen and the test speed could be mathematically evaluated and clear correlations could be found.
- As for the influence of the diameter, it was found that the shear stress values for all temperatures tested with cores of 150 mm diameter were lower than the results of the test carried out with 100 mm asphalt cores.

Table 4. Influence of the sample age on shear stress.

Laboratory	1		2	
Test conditions	D = 150 mm, v = 50 mm/min, normal stress = 0 MPa		D = 100 mm, v = 2.5 mm/min, normal stress = 0.2 MPa	
Test date	May 2006	November 2007	June 2006	November 2007
Temperature	Shear stress (MPa)			
10°C	2.03	2.49	0.95	1.09
20°C	1.23	1.59	0.68	0.68
30°C	0.58	0.98	0.37	0.44

– The presence of emulsion seems to mitigate the scatter of shear stress at the interface.
– A relationship was found that allows to estimate the influence of the test speed on shear stress.
– Friction parameter appeared to be approximately linearly dependent on normal stress. This was also true for the slope of the linear regression between shear stress with and without normal stress.
– Regardless of the interface conditions, the interlayer shear stress appears to follow the same temperature dependency.
– Within 18 months before first and second sampling, an increase of the shear stress with sample age was found.

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