INTERLAYER SHEAR PERFORMANCE: EXPERIENCE WITH DIFFERENT PAVEMENT STRUCTURES

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ABSTRACT

Maintenance strategies are often based on surface characteristics and distress phenomena without determining the interlayer adhesion properties on a regular basis. This is remarkable as the adhesion between different layers is a very important factor for the performance and the service life of pavements. In this paper recent Swiss experience with this important property is discussed and demonstrated.

The paper focuses on interlayer properties between the different asphalt concrete pavement courses and the influence of water on the adhesion. A second aspect concentrates on old concrete pavements rehabilitated with asphalt and an intermediate layer consisting of a wire mesh, a glass or polymer fiber geotextile or a bituminous treatment. In addition the adhesion performance of some Swiss motorway sections is discussed

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Keywords: Adhesion, performance, interlayer bond, pavements, direct shear, water sensitivity,

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1. INTRODUCTION

With growing road maintenance and rehabilitation efforts worldwide, technical tools for timely, comprehensive and cost-effective assessment of the structural condition of pavements become more and more important. So far, maintenance strategies are often based on surface characteristics and distress phenomena without determining the interlayer adhesion properties on a regular basis. This is remarkable as the adhesion between different layers is a very important factor for the performance and the service life of pavements. Figure 1 demonstrates that adhesion problems not only occur between surface and base courses but also between deeper layers (i.e. between base courses or between base course and bituminous or cementitious subbase). In many cases problems with the interlayer bond seem to be already a result of the construction process (insufficient compaction energy, too thick layers compacted in one single process, temperature or rain problems, soiled surface). These problems lead to poor pavement performance particularly in cases where water can penetrate between the poorly adhering layer interfaces. In this paper recent Swiss experience with interlayer adhesion property is discussed and demonstrated.

The paper focuses on interlayer properties between different asphalt concrete pavement courses and the influence of water on the adhesion. A second aspect concentrates on old concrete pavements rehabilitated with asphalt and an intermediate bituminous layer with and without steel wire grid or glass fiber mesh reinforcement. In addition the adhesion performance of some Swiss motorway sections with usual tack coat treatment is discussed.

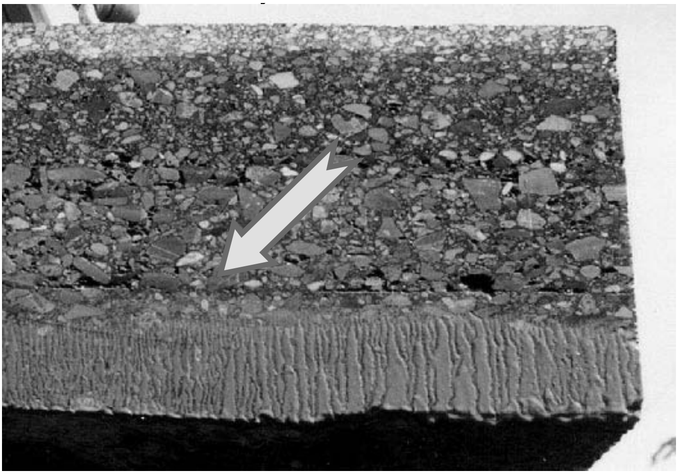


Figure 1: Interlayer adhesion problem between base course and subbase course in a slab taken from a newly built Swiss motorway.

2. ADHESION TESTING WITH THE LAYER-PARALLEL DIRECT SHEAR DEVICE

For the testing described in the paper the Layer-Parallel Direct Shear Device (LPDS) was used. In some cases also direct tension adhesion tests (pull-off tests) were performed due to the fact that under service conditions adhesion of surface courses is not only effective in the shear but also in the tension mode (Figure 2)

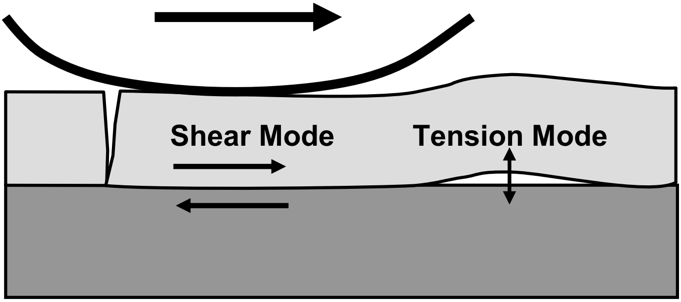


Figure 2 Adhesion stress modes in the upper pavement layers under service conditions

The Layer-Parallel Direct Shear (LPDS) test device (figure 3) is an EMPA modified version of equipment developed in Germany by Leutner (1979). The modified LPDS test device fits into an ordinary servo-hydraulic Marshall testing machine and allows testing of cores with a diameter of about 150mm [3, 7].

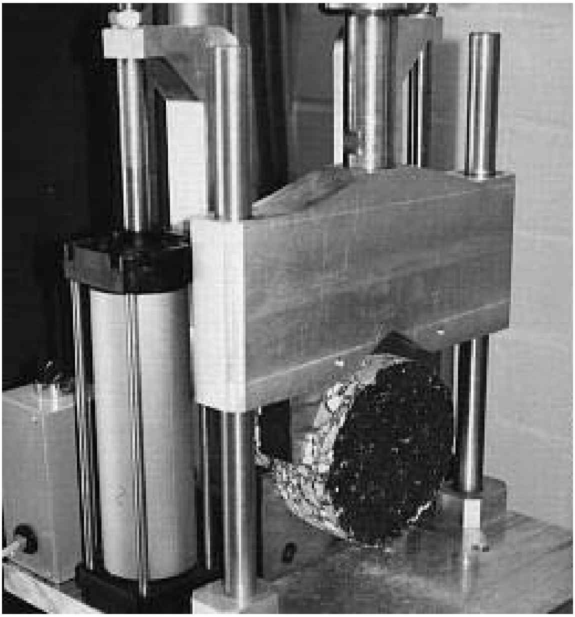
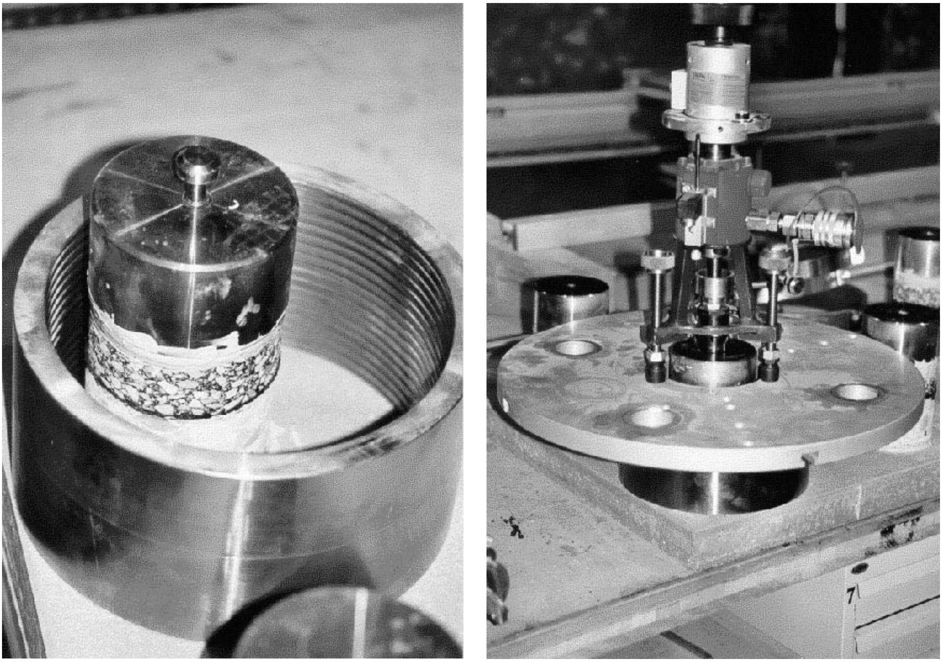


Figure 3: LPDS (Layer-Parallel Direct Shear) test device constructed by EMPA for use in a servo-hydraulic testing machine

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, remains unsuspended. Shear load is induced to the core head by a semicircular shear yoke with a deformation rate of 50.8mm/min, thus producing fracture within the pre-defined shear plane. The EMPA modified LPDS has a long clamping and supporting length such that the clamping of the specimen is simple, fast and well defined. This is particularly beneficial when testing different shear layers in a core or when testing pre-heated test specimens as it minimizes temperature loss. In order to achieve a homogeneous load distribution the yoke and clamps are adjustable to accommodate core diameters from 148 mm to 155 mm. Since 2000 the LPDS is described in the Swiss standard SN 671961 “Bituminöses Mischgut, Bestimmung des Schichtenverbunds (nach Leutner)” [1].

3. ADHESION TESTING WITH THE PULL-OFF DEVICE

The pull off test is carried out according to the German testing specification ZTV-SIB 90 [2]. Divergent to this specification the test disc diameter is 100 mm. The test is conducted with a testing speed of 300 N/s and a perforce of 100 N is applied. For testing in a first step cores are glued on a concrete plate. After that the steel test disc with a diameter of 100 mm and a thickness of 60 mm is fixed on top of the core. Figure 4 shows the test device modified for testing cores by using an aluminium plate with a hole in the middle on top of a steel ring.



a) **b)**

Figure 4 a, b): Pull-off test device modified for testing cores

4. SHEAR FORCES BETWEEN UPPER AND LOWER BASE COURSE

Normally, when tested, the interlayer adhesion properties are determined between surface and base course, whereas in the following investigation the focus is on the adhesion strength between two base layers. The cores were taken at 16 different sites mostly from Swiss motorways in different Swiss cantons and have also been investigated in the research project "Methods for assessment of interlayer bonds"[3]. The advantage of this procedure was that a great variety of practically used base courses could be investigated. The disadvantage was the fact that in many cases no information about the composition of the individual layers was available as the pavement consisted of old and sometimes undefined layers according to an older Swiss standard [4]. There are 3 different configurations: 1. new/new, 2. new/old and 3. old/old. The shear force between upper and lower base course was determined for at least 7 specimens at a temperature of 20°C. Table 1 shows the results for the maximal shear force.

Coring Site	Configuratio	Material		Max. Shear Force [kN] (mean value N≥7)	Max. Shear Stress (mean Value) [N/mm2]
		Upper Base Course	Lower Base Course		
1	old/old	HMA (old, undefined)	HMA (old, undefined)	21.4	1.21
2		HMA (old, undefined)	HMA (old, undefined)	26.8	1.52
3		HMA (old, undefined)	HMA (old, undefined)	27.1	1.53
4		HMA (old, undefined)	HMA (old, undefined)	12.3	0.70
5	new/old	CSHM22*	HMA (old, undefined)	32.3	1.83
6		HMA 32	HMA 32 (old)	25.8	1.46
7		HMA 22	HMA 30 (old)	19.0	1.08
8		HMA 22	HMA (old, undefined)	10.7	0.61
9	new/new	CSHM22*	HMA 32	30.4	1.72
10		HMA 32	HMA 32	23.9	1.35
11		HMA 22	HMA 32	16.1	0.91
12		HMA 22	HMA 32	29.3	1.66
13		HMA 22	HMA 22	17.3	0.98
14		HMA 22	HMA 32	7.3	0.41
15		HMA 22	HMA 32	36.0	2.04
16		HMA 16	HMA 22	33.2	1.88
Mean Value				23.1	1.31
Standard				8.6	0.49

Table 1: Coring sites with max. shear force between upper and lower base course tested at 20°C
* High Moduli HMA

The mean value for all coring sites results in a shear force of 23.1kN ± 8.1kN. A classification of the coring sites taking into consideration whether the pavement was of a certain age (old/old), whether it had been partly (old/new) or totally rehabilitated (new/new) results in the mean values given in table 2. By looking at the table no significant difference between the classes can be established.

Coring site	Material		Max. Shear Force (Mean Value) [kN]	Standard Deviation [kN]	Max. Shear Stress (Mean Value) [N/mm²]
	Upper Base Course	Lower Base			
1…4	old	old	23.6	6.2	1.34
5…8	new	old	22.0	9.3	1.24
9…16	new	new	24.2	9.9	1.37

Table 2: Max. shear forces in the interlayer between upper and lower base course tested at 20°C

Figure 5 depicts the relative frequency for different classes of the mean and the single values. The decline at class 21 to 25kN of the frequencies graph for the mean value does not show up in the frequencies graph for the single values, a fact that can be explained by the smaller number of values.

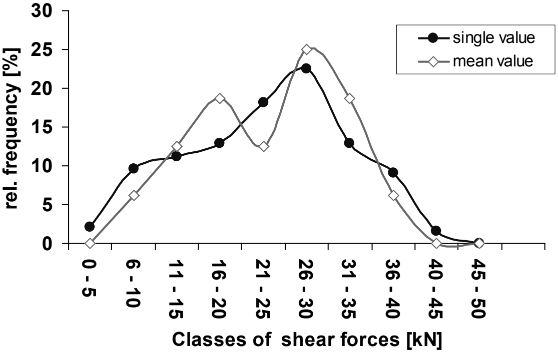


Figure 5: Frequency distribution of the shear forces between upper and lower base course

The results show unexpectedly high values of shear forces between to base course, especially with respect to the Swiss Standards which only require a minimum of 12kN. In the framework of this research only two values (10.7 kN and 7.3 kN) or 6.3% of the coring sites fell below this limit. For more than 80% of the coring sites the determined shear values are above 16kN and for 56% of the sites the values are more than 20kN (see figure 5).

5. ADHESION AFTER PAVEMENT REHABILITIONS

Although during resent years a lot of old concrete pavements have been rehabilitated with bituminous overlays using systems with so called stress absorbing membrane interlayers (SAMI), the question how such interlayers effect the shear bond could not be answered clearly. Moreover, in many cases, pavement rehabilitations with geotextiles proved to be unfavourable to adhesion properties.

In a research carried out by the Swiss federal road authority ASTRA [5] a 30 year old concrete pavement of a motorway test section was rehabilitated with an asphalt surface layer (either Stone Matrix Asphalt SMA 11 or Asphalt Concrete AB 11) using three different intermediate bituminous layers

- Glass fibre mesh reinforcement
- Steel wire grid reinforcement
- without reinforcement

Before the application of the glass fibre mesh, in a first step, a hot tack coat was sprayed on the concrete pavement. After that the glass fibre mesh was unrolled lane wise with a machine and pressed to the ground with a brush. Then the stone matrix asphalt was build (thickness 4 cm).

The second system consisted of a steel wire grid reinforcement and slurry generally used for cold micro surfacings. In this case the steel wire grid was directly applied on the concrete pavement, one end being mechanically fixed to the ground, and flattened with a roller compactor. The slurry (thickness 0.5 to 1cm) was applied onto the steel wire grid and after the breaking of the emulsion the surfacing was finished with the application of a stone matrix layer (thickness 4.5cm).

For the bituminous interlayer without reinforcement a hot tack coat was applied and spread with gravel, which was compacted afterwards. After sucking off the surplus gravel, a 4 cm asphalt concrete surface layer was applied.

Testing of the interlayer adhesion was conducted with the Layer-Parallel Direct Shear Device (LPDS) and the modified pull-off device according to the Swiss standard [1] or the German testing specification [2] and the description in Sections 2 and 3. All results are shown in table 3.

Specime	Test method	reinforceme	Max. Shear	Max. Pull-off	Max. Shear Stress	Max. Pull-off Stress
#			[kN]	[kN]	[N|mm^2]	[N|mm^2]
1	Direct Shear	Glass fibre	6.84		0.39	
2	Direct Shear	Glass fibre	6.13		0.35	
3	Direct Shear	Glass fibre	7.70		0.44	
4	Direct Shear	Glass fibre	5.82		0.33	
11	Direct Shear	Steel wire	1.27		0.07	
12	Direct Shear	Steel wire	2.07		0.12	
13	Direct Shear	Steel wire	4.10		0.23	
19	Direct Shear	No	14.35		0.81	
20	Direct Shear	No	16.12		0.91	
21	Direct Shear	No	15.53		0.88	
22	Direct Shear	No	15.78		0.89	
5	Pull-off	Glass fibre		2.86		0.36
6	Pull-off	Glass fibre		2.89		0.37
7	Pull-off	Glass fibre		2.67		0.34
23	Pull-off	No		6.0		0.78
24	Pull-off	No		6.28		0.80
25	Pull-off	No		6.58		0.84

Table 3: Max. shear and pull-off force and stress 20°C for different bituminous interlayers

Regarding the Layer-Parallel Direct Shear testing for each surface layer 4 cores were used; in case of the steel wire grid the result is the mean value of three cores. The Pull-off tests could only be conducted for samples with glass fibre mesh and without reinforcement. All specimens with steel wire reinforcement were already broken before testing. For pull-off tests three samples were taken and the mean value was calculated. All testing was carried out at a temperature of 20°C.

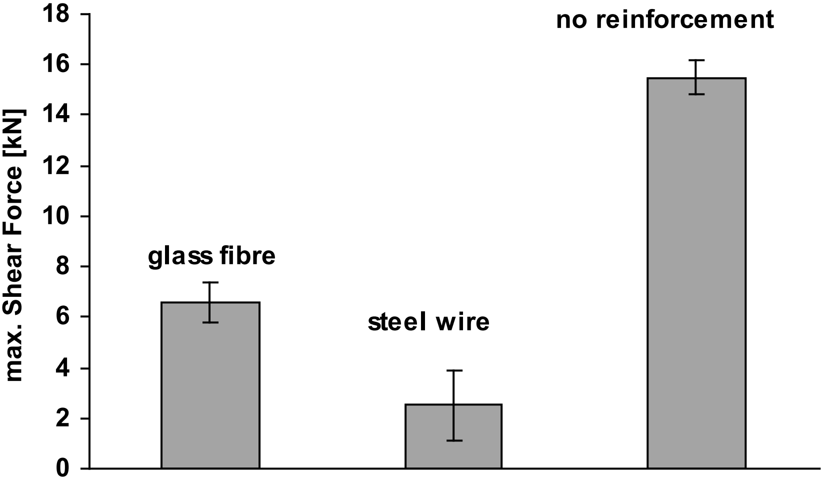


Figure 6: Direct shear test results at 20°C for different bituminous interlayers.

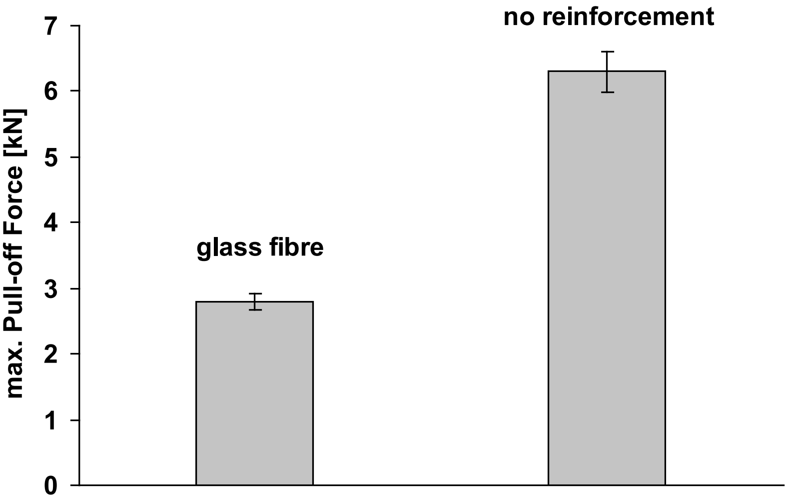


Figure 7: Pull-off test results at 20°C for different bituminous interlayers.

The results of the direct shear test in figure 6 clearly indicate a vast difference between the different systems. The cores with the steel wire reinforcement achieve only values between 1.3kN and 4.1 kN (mean value: 2.5kN) and show a relatively big scatter (standard deviation: 1.4kN) which can be attributed to the unfavourable relation between grid size and core diameter. This can clearly be seen in figure 8. For specimens with glass fibre mesh reinforcement the shear force values range between 7.7kN and 6.1 kN (mean value: 6.6kN, standard deviation: 0.8kN), whereas the values for the specimens with unreinforced bituminous interlayer come up to a mean value of 15.4 kN (single values between 14.4kN and 15.8kN, standard deviation: 0.7kN).

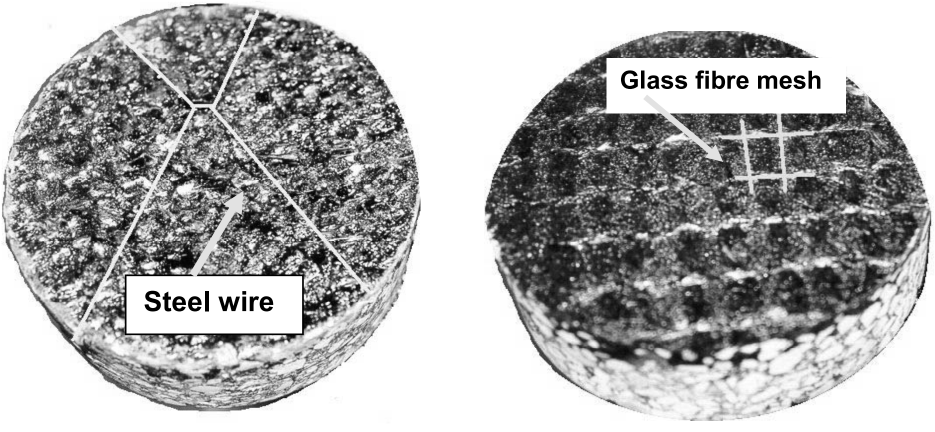


Figure 8: View on the surface of the interlayer after testing, showing the steel wire grid (left), and the glass fibre mesh reinforcement (right)

Pull-off testing leads to similar results (see figure 7). For the specimens with glass fibre reinforcement pull-off forces between 2.7 kN and 2.9 kN (mean value: 2.8kN, standard deviation: 0.12kN) were achieved and for the specimens without reinforcement the shear forces came up to 6.6 kN(mean value: 6.3kN, standard deviation: 0.31kN). Pull-off testing and shear testing give the same ranking for the specimens with glass fibre reinforcement and with no reinforcement. The fact that specimens with steel wire reinforcement already broke by coring clearly indicates an insufficient bond within the pavement. Regarding the test results the investigation indicates that the use of steel wire and glass fibre mesh reinforcement can be critical and in case of application both systems have to be handled carefully and checked on periodically.

6. THE EFFECT OF WATER ON THE SHEAR STRENGTH OF ASPHALT

The effect of water on the interlayer shear strength of asphalt pavements is still a widely unexplored subject. Thus, a first study was started at EMPA in 2001[6]. The purpose of the study was to evaluate the influence and effect of water on the shear strength of asphalt pavements. Experiments and tests were conducted according to a test method specially developed at EMPA. Results and findings are presented below.

Testing was carried out on cores taken from an asphalt concrete pavement slab containing three layers. As the pavement consisted of a 20 years old pavement the composition of the individual layers was not available any more. It was discovered that the shear strength between the surface and adjacent lower layers was so poor that the influence of water could not be tested. As a result, the shear strength between the base layers was determined. To generate water penetration between the layers, a hole of 25 mm was drilled from top of the core and a short pipe was glued inside. The pipes were connected to a pump by hoses, as seen in Figure 9. The figure shows the testing set up for six cores:

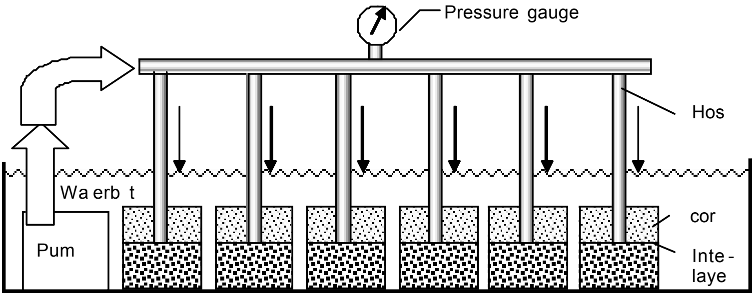


Figure 9: Experiment set-up

The cores were then placed in a bath containing water at 40°C and water pressure was applied to force the water between the interface. The cores remained in the bath for a given amount of time with a given pressure, after which they were placed in a water bath of 20°C in order to cool down. The specimens were then tested for shear strength at 20°C using the LPDS device.
The data obtained from the five different tests, each with varying pressure, temperature and time immersed in water, are presented in table 4 and figure 10 below.

Test	Specimen	Pressure	Storage Time in	Shear Force	Shear Stress
#	#	[bar]	Water at 40°C [hrs]	[kN]	[N/mm2]
1	53	0	0	25.15	1.42
1	64	0	0	29.21	1.65
1	52	0	0	26.37	1.49
2	51	0.5	5.5	22.19	1.26
2	59	0.5	5.5	22.76	1.29
2	26	0.5	5.5	24.15	1.37
2	27	0.5	5.5	21.53	1.22
3	43	0.55	8	19.05	1.08
3	48	0.55	8	21.2	1.20
3	49	0.55	8	22.14	1.25
3	4	0.55	8	19.51	1.10
4	36	0.5	8	20.39	1.15
4	5	0.5	8	19.15	1.08
4	1	0.5	8	19.08	1.08
4	6	0.5	8	21.05	1.19
5	42	0	75	14.54	0.82
5	41	0	75	18.95	1.07
5	34	0	75	23.98	1.36
5	45	0	75	21.25	1.20
5	2	0	75	19.21	1.09

Table 4: Test results and conditions

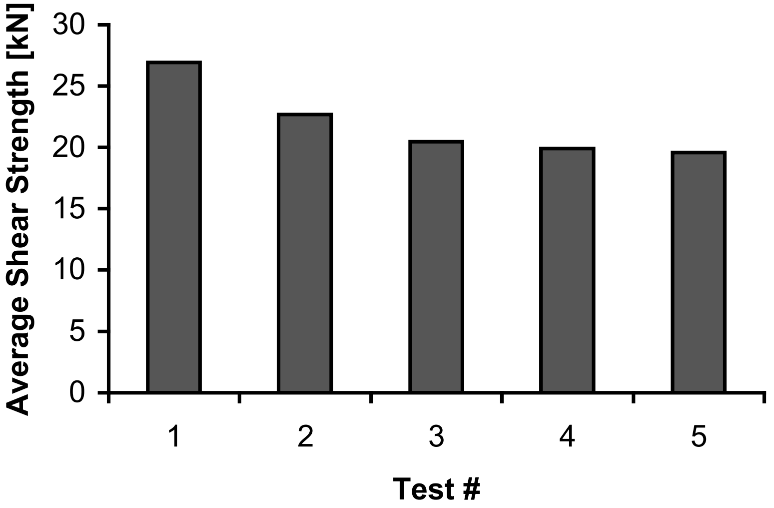


Figure 10: Average shear strength after different types of conditioning and loading

From the results follows, that the presence of water does have a clear effect on the shear strength. Each of the tests showed a decrease of 15…27% in shear strength when compared with Test #1 (without water immersion), which acted as reference. In addition, the results indicate that a significant immersion time in water without pressure gives approximately the same results as applying pressure for a short period of time (e.g. 8 hours water immersion by a pressure of 0.5 bar, test # 4) as seen by figure #7. Although the test results need verification by testing other pavement types, it seems reasonable to combine adhesion testing with water sensitivity testing. Therefore, it is recommended that future tests should simply use water immersion at 40°C rather than pressure, due to the difficulties mentioned above.

7. CONCLUSIONS

The results described in this paper clearly indicate the importance of the interlayer shear performance and show that still a lot of unanswered questions remain for future research. Besides the adhesion problems when using stress absorbing intermediate bituminous layers with steel wire grid or glass fibre mesh reinforcement, it is important to note that the application of such stress absorbing interlayers and the combination of different materials may always lead to difficulties regarding the interlayer bond. In case of using stress absorbing intermediate bituminous layers it is important to choose appropriate and sufficiently established systems and construction techniques in order to minimize negative effects on adhesion.

Stress absorbing interlayers SAMI are often applied on cracked pavement. This causes another difficulty that has to be dealt with: Water can penetrate through the cracks in the lower layer into the contact zone between the layers and produce a negative effect on the performance of the whole pavement structure.

As for asphalt pavements without SAMI, interlayer water sensitivity should also be taken into consideration. This could be done according to the method developed by EMPA on basis of a 75 hours water emersion at 40°C.

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