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Experimental Investigations of Moisture Damage in Asphalt

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Abstract: The objective of the presented investigation was to verify findings that moisture has a negative effect on the bond force leading to a reduction of the mean maximum shear force up to 30% for long term water storage or combined pressure and short term water storage at 40°C. Additionally, the influence on maximum shear stiffness was investigated. Furthermore, it was assumed that the reduction of shear properties would increase with higher applied temperature. The investigation was conducted using different up to date pavement structures for urban roads and heavy trafficked motorways. The chosen material represents the actual Swiss construction practice favoring relatively open graded low noise surface courses. Testing was done using the Layer-Parallel Direct Shear device (LPDS) and the Shear Box as an additional measure for the shear properties. The results showed that 72h water conditioning at 40°C reduces interlayer shear strength by 2% to 20%. 72h water conditioning at 60°C is more severe, reducing strength by 15% to 25% and stiffness by 14% to 30%.

***Key words**: Interlayer shear bond, Moisture damage.*

Introduction

Moisture is known to accelerate the reduction of the long term performance of asphalt pavements caused by rutting, ravelling or cracking. In fact, numerous investigations and research projects dealt with this subject by focussing on the behaviour and moisture resistance of asphalt mixtures and pavement materials [1-6]. However, focus of research is surprisingly different with respect to the influence of moisture on interlayer bonding: Here the connection between interlayer bonding and its relation to moisture and climate have not often been studied in great detail. The present paper reporting on experimental investigations of moisture damage in asphalt pavement focuses on the effect of water on the interlayer bond.

As shown schematically in Fig. 1 moisture has an important influence on the damage process of asphalt pavements. On the one hand, water penetrating through holes and cracks into the pavement structure can weaken or destroy the adhesion between the different pavement layers, and on the other hand, there is the so-called stripping effect that acts locally within the material but can also lead to a deterioration of the bond.

Earlier, it was shown in an investigation by Raab and Partl [7] that the influence of moisture had a negative effect on interlayer bonding and that moisture can lead to a decrease in shear force between 15% and 27% (see Fig. 2). Further, it was found that the reduction in shear force caused by long term water storage of 75h at 40°C was equal to short term storage of 8h combined with a pressure of 0.05 MPa [7, 8]. The material used in these investigations consisted of field cores from a motorway construction with SMA 11 surface or AC 22 base course. For both layers the air void content was about 4 vol-%.

The objective of the presented investigation was to verify these findings and to prove that moisture has a negative effect on the bond force leading to a reduction of the mean maximum shear stress for long term water storage or combined pressure and short term water storage at 40°C. Additionally, the influence on maximum shear stiffness was investigated. Furthermore, it was assumed that the reduction of shear properties will increase with higher applied temperature.

Testing

Testing was done using two different devices: The Layer-Parallel Direct Shear (LPDS) and the Shear Box device which allowed the application of different horizontal normal loads.

The LPDS test device (Fig. 3) is an EMPA modified version of equipment developed in Germany by Leutner being more versatile in the geometry and more sophisticated in the clamping mechanism, [9, 10].

For Shear Box testing the Shear Box at the ETH Institute of Geotechnical Engineering was used. The ETH Shear Box operates on the same principle as the Ancona Shear Testing Research and Analysing Apparatus ASTRA which was constructed for the determination of the shear bond between asphalt pavements in the early 1990 ties [11]. As opposed to the ASTRA device, the Shear Box at ETH is normally used for testing of soil samples. Therefore, the attainable forces as well as the applicable normal loads are limited to the needs of this type of application. The Shear Box test device (see Fig. 4) consists of two metal rings ② of 100 mm diameter in which the specimen ① is placed. These rings are placed and fixed inside a lower and an upper pressure plate ⑧. The lower pressure plate is shifted horizontally with a constant displacement rate of 2.5 mm/min while the upper plate is fixed. The normal load perpendicular to the shear plane is applied hydraulically by a jack cylinder ⑤ which presses the pressure plates against a yoke ③.

Additional to the shear force the maximum slope from the diagram of shear force F versus shear deformation w can be used to define the maximum shear "stiffness" value S as follows Eq. (1):

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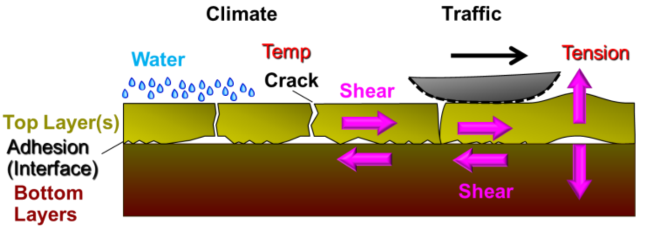

Fig. 1. Schematic Drawing of Interlayer Damage Mechanisms.

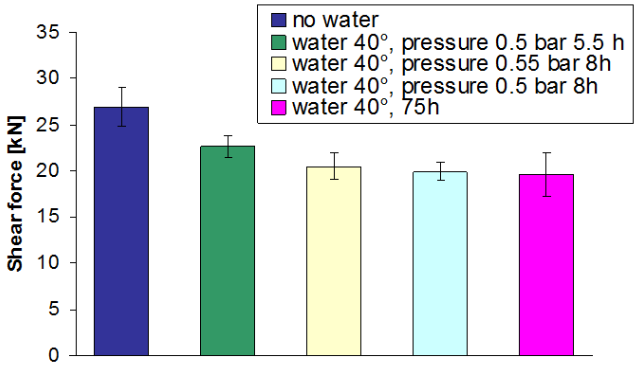

Fig. 2. Influence of Water Conditioning on Interlayer Shear Properties.

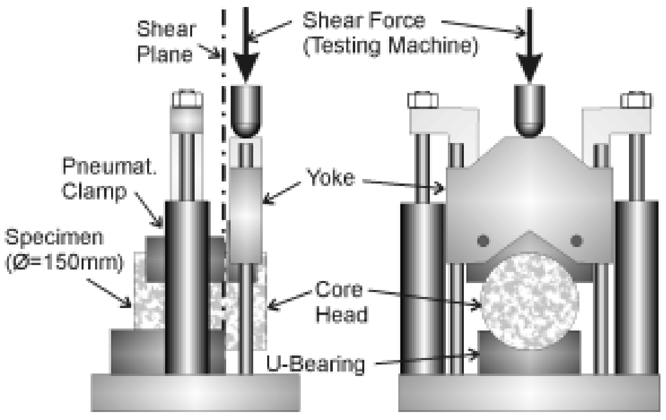

Fig. 3. LPDS Test Device, Schematic Drawing.

$$S_{\max} = \frac{dF}{dw(F)} \quad \text{at} \quad \frac{d^2F}{dw^2} = 0 \quad \text{and} \quad \frac{d^3F}{dw^3} < 0 \tag{1}$$

where:

dF = differential shear force

dw = differential shear deformation

In order to be able to compare “stiffness values” for different specimen diameters the shear reaction modulus K [12] is used Eq. (2):

$$K_{\max} = \frac{d\tau}{dw(\tau)} \quad \text{at} \quad \frac{d^2\tau}{dw^2} = 0 \quad \text{and} \quad \frac{d^3\tau}{dw^3} < 0 \tag{2}$$

where:

$d\tau$ = differential nominal shear stress

$dw(\tau)$ = differential shear deformation

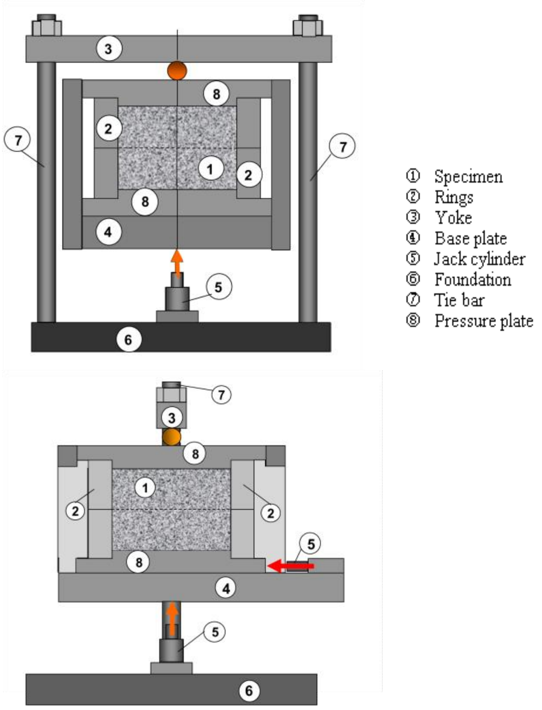

Fig. 4. ETH Shear Box Dice, Shematic Dawing.

Material and Testing Program

Since the material for the previous investigations had been taken from an old remaining pavement slab, the investigation was conducted using different up to date pavement structures for urban roads and heavy trafficked motorways. The chosen material represented the actual Swiss construction practice favoring relatively open graded low noise surface courses.

The use of urban pavement structures with comparatively thin (30 mm) surface courses further allowed the application of the Shear Box as an additional measure for the shear properties. For the urban pavement structures (Pavements 1 and 2), material was taken from two or three layered pavement slabs of 1.10 m by 0.70 m, which had been taken prior to trafficking. The urban pavements had been constructed in 2001 and slabs had been stored thereafter at 20℃ and 60% humidity until 2009. Both urban pavements had been constructed according to the Swiss standard [13]. The surface courses were thin hot mix surface courses. The surface course of pavement 1 consisted of a stone mastic asphalt SMA with a maximum aggregate size of 8 mm and the one of the second pavement of a special low noise pavement AC MR (Swiss low noise pavement SN 640 431-1b NA [16]) with a maximum aggregate size of 8 mm. The second layer of pavement 1 was an asphalt concrete AC with a nominal maximum aggregate size of 16 mm. For pavement 2 asphalt concrete AC with a nominal maximum aggregate size of 32 mm was used. Pavement 1 had a third layer consisting of asphalt concrete AC with a nominal maximum aggregate size of 16 mm. Material characteristics are given in Table 1. In case of LPDS testing the interlayer shear properties were determined at all existing interfaces, while Shear Box testing could only be done between the thin surface and the binder course.

The material from pavement 3 was taken from a newly

Table 1. Material Caracteristics of Pavements 1 and 2.

Pavement No.	1			2	
Layer No.	1	2	3	1	2
Layer Type	SMA 8	AC 16	AC 22	AC MR 8	AC 32
Layer Thickness [mm]	30	50	60	30	100
Binder Type	70/100	55/70	55/70	70-100	55/70
Additives	None	None	None	NAF501*	None
Binder Content [mass-%]	6.9	5.3	6	6.5	3.7
Marshall Test					
Stability [kN]	7.9	14.6	14	13	13
Flow [mm]	2.3	2.2	2.5	2.7	2.5
Air Void Content [vol-%]	3.4	4.6	3.1	11.2	4.7
Air Void Content Cores [vol-%]	10.2	5.1	4.8	11.5	2

* Trinidad lake asphalt and fibres

Table 2. Material Characteristics of Pavement 3.

Pavement No.	3		
Layer No.	1	2	3
Layer Type	AC MR 8	AC B 22 H	AC T 22 H
Layer Thickness [mm]	40	80	80
Binder Type	PmB-E 45/80-65	PmB-E 10/30-70	PmB-E 10/30-70
Binder Content [mass-%]	6	4.8	4.4
Marshall Test			
Stability [kN]	10.1	15	15
Flow [mm]	3.1	4.5	4.5
Air Void Content [vol-%]	6.5	5.5	5.5
Air Void Content Cores [vol-%]		4.3	4.7

Fig. 5. Coring of Pavement 3.

Table 3. Testing Conditions.

Condition No.	Water Temperature [℃]	Storage Time [h]	Water Pressure [MPa]
1	No water	None	None
2	40	72	None
3	60	72	None
4	40	5	0.05

constructed motorway in autumn 2009 (see Fig. 5). Its surface course consisted of a low noise pavement MR with a maximum

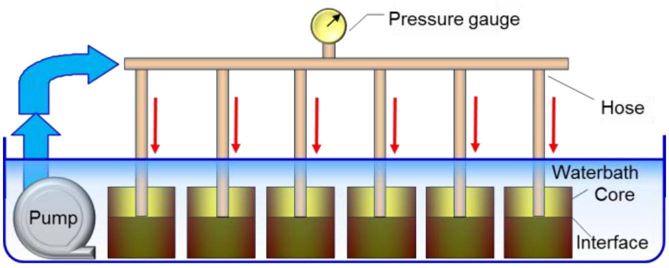

Fig. 6. Water-pressure Conditioning Set-up (Schematic).

aggregate size of 8 mm (see Table 2). The second layer was an asphalt concrete binder course AC B with a nominal maximum aggregate size of 22 mm and for the third layer an asphalt concrete base course AC T with a nominal maximum aggregate size of 22 mm was used. Since the pavement consisted of three layers, the interlayer shear properties were determined with LPDS at the interface between surface and binder (interface 1) and between binder and base course (interface 2). For shear testing, the LPDS test device was used for all three pavements and all existing interfaces. The investigation of the shear properties between the first and second layer of pavements 1 and 2 without and with water conditioning at 40℃ (without pressure) was also done using the Shear Box. In case of LPDS shear testing the air void content was determined for every single core and layer.

In order to evaluate the influence of moisture on the interlayer shear properties, the following conditions according to Table 3 were chosen.

In case of pure water conditioning (conditions No. 2 and No. 3), the specimens were first stored in a water bath at 40℃ or 60℃, where they remained for the given amount of time according to Table 3. After this, they were sealed in plastic bags to prevent the evaporation of moisture and conditioned at 20℃ for at least 8h in a temperature chamber. For the pressure conditioning (condition No. 4) a special test set-up was used. To allow the water action between the layers, a hole of 25 mm was drilled onto the interface of each core to be tested and a short length of pipe was glued inside. In order to ensure that the glue would not seal the pipe off, a small plastic ring was inserted. The pipes were connected to a pump by hoses, as seen in Fig. 6. The specimens were then placed in a bath containing water at 40℃ and water pressure of 0.05 MPa was applied to the interface. After conditioning, the specimens were again put into plastic bags and stored for at least 8h in a temperature chamber at the LPDS test temperature of 20℃. Apart from pavement 2, which, because of a lack of material, could not be tested at condition No. 4 (pressure) all pavements were tested at all interfaces and all test conditions using LPDS. As mentioned earlier, the first interface of pavements 1 and 2 were additionally tested with the Shear Box for conditions No. 1 and No. 2.

The detailed testing program is depicted in Fig. 7.

Test Results and Discussion

Pavements 1 and 2, interface 1: Shear Box

Shear Box testing without water conditioning was conducted without and with 2 different normal stresses of σ_n = 0.1 and 0.4

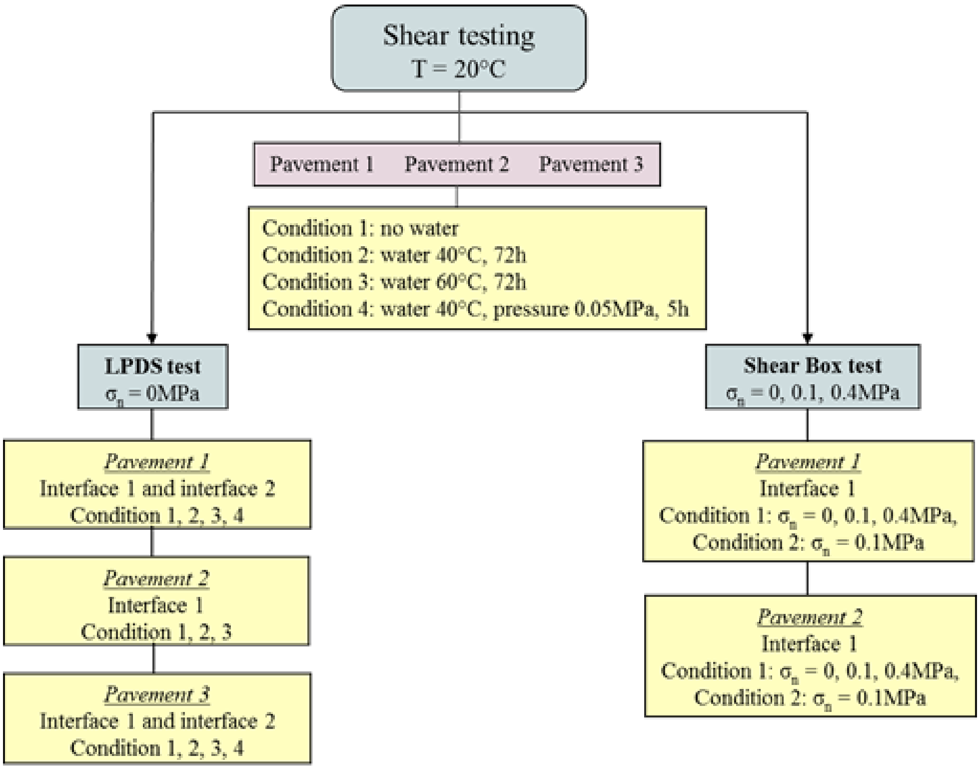

Fig. 7. Detailed Testing Program.

Table 4. Mean Values of Shear Box Test Results for Pavements 1 and 2, Interlayer 1; Standard Deviation in Brackets.

Condition No.	σ_n [MPa]	F_{max} [kN]	τ_{max} [MPa]	w at F_{max} [mm]	S_{max} [kN/mm]	K_{max} [MPa/mm]
			Pavement 1, Interface 1			
	0	9.1 (1.42)	1.2 (0. 19)	3.5 (0.43)	3.5 (0.75)	0.2 (0.04)
1	0.1	8.9 (0.90)	1.2 (0.12)	2.7 (0.31)	3.8 (0.42)	0.2 (0.06)
	0.4	10.6 (1.67)	1.4 (0.22)	3.2 (0.52)	4.5 (0.14)	0.3 (0.1)
2	0.1	8.7 (1.95)	1.1 (0.25)	3.9 (0.29)	3.0 (0.59)	0.2 (0.06)
			Pavement 2, Interface 2			
	0	9.2 (1.02)	1.2 (0.13)	2.9 (0.31)	3.7 (0.24)	0.2 (0.02)
1	0.1	10.3 (1.28)	1.3 (0.17)	3.9 (0.56)	3.0 (0.44)	0.2 (0.02)
	0.4	10.6 (0.97	1.4 (0.13)	3.3 (0.47)	3.9 (0.69)	0.2 (0.04)
2	0.1	7.4 (0.71)	1.0 (0.09)	3.3 (0.66)	2.7 (0.38)	0.2 (0.04)

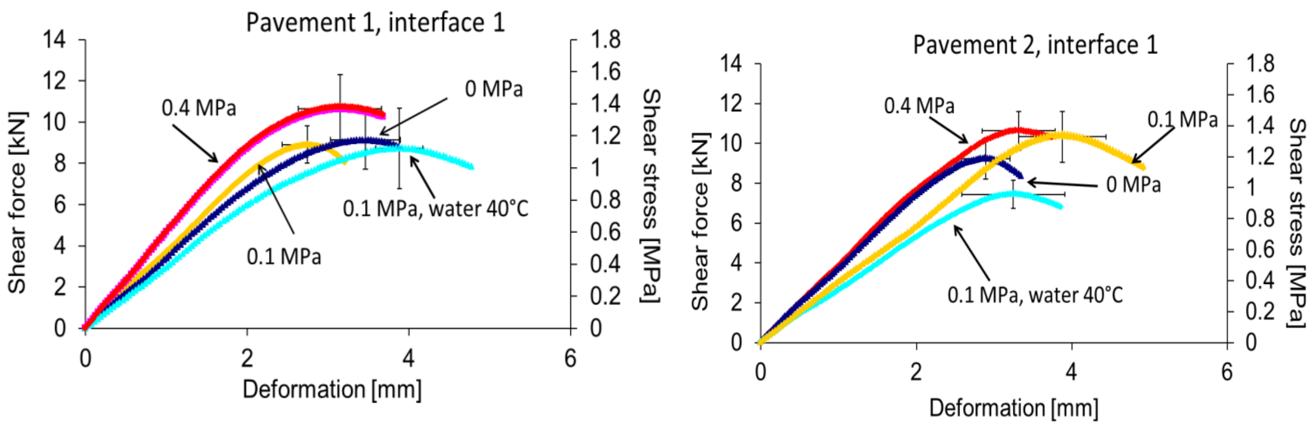

Fig. 8. Mean Shear Force (Stress) – Deformation Curves for ETH Shear Box Testing at 20℃ of Pavements 1 and 2, Interface 1 for Different Normal Stress and Conditioning.

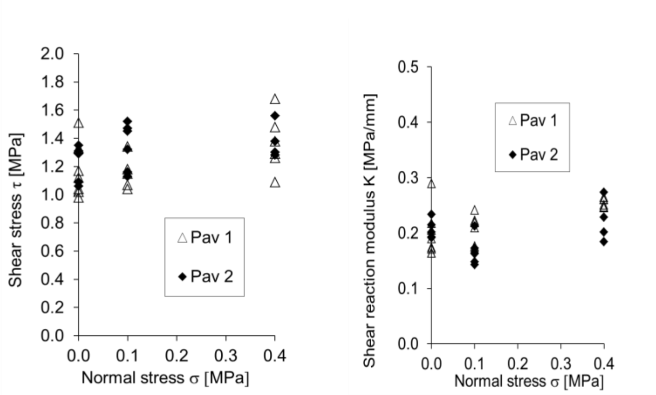

Fig. 9. Mean Shear Force (stress) – Deformation Curves for ETH Shear Box Testing at 20℃ of Pavements 1 and 2, Interface 1.

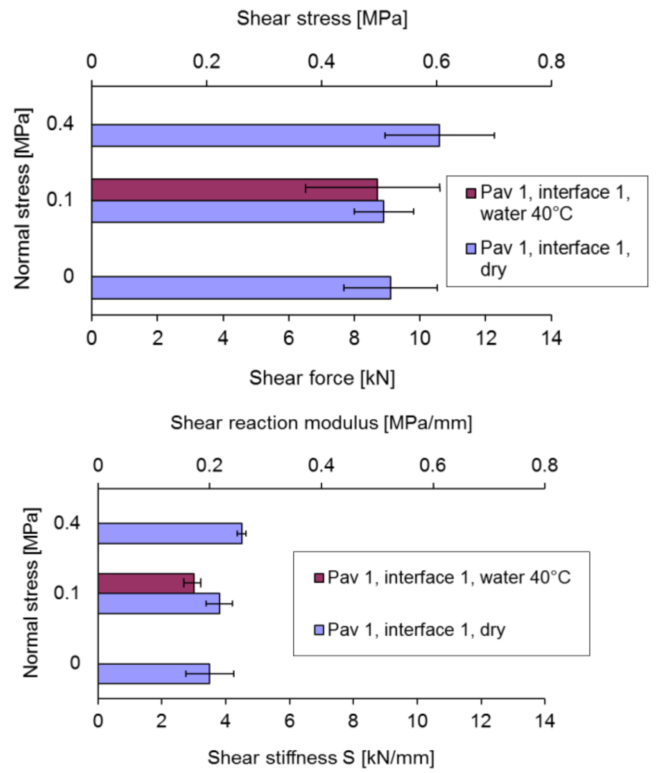

Fig. 10. Maximum Shear Force and Stiffness for Different Normal Stresses for Pavement 1, Interface 1, Conditions 1 and 2.

MPa. For condition No. 2 (water storage at 40℃, 72h) a normal stress ofσ_n = 0.1 MPa was applied. The test results (mean values, standard deviation in brackets are given in Table 4.

Fig. 8 depicts the mean shear force (stress) – deformation curves. Fig. 9 shows the maximum shear stress and the shear reaction modulus *K* linear regression lines for the Shear Box testing of pavement 1 and 2 at different normal stresses.

According to Fig. 9a, the scatter between the single shear stress test results for both pavements is quite large and therefore the coefficient of determination R^2 is extremely low. As mentioned earlier for pavement 1, the difference between results at normal stresses 0 MPa and 0.1 MPa is not big, whereas for testing at 0.4 MPa there is a clear increase compared to σ_n = 0 MPa or 0.1 MPa.

The test results for pavement 1 show no big differences for testing without and with normal stress σ_n of 0.1 MPa as shown in Fig. 10a. The shear force (stress) when testing at normal stress σ_n = 0.1 MPa is even a little bit lower (8.9 kN/0.9 MPa) than the test results without normal stress (9.1 kN/1.42 MPa). When testing with a normal stress of 0.4 MPa the shear force (stress), and the shear stiffness *S* increase to 10.6 kN respectively from 3.5/3.8 kN/mm to 4.5 kN/mm (see Fig. 10b). Testing after water conditioning and with a normal stress of 0.1 MPa leads to 8.7 kN (1.1 MPa), *i.e.* the lowest shear force (stress) values. However, this decrease is not statistically significant since the difference is smaller than the standard deviation. This is different in case of the shear stiffness (shear reaction modulus), where the change after moisture immersion is more distinct.

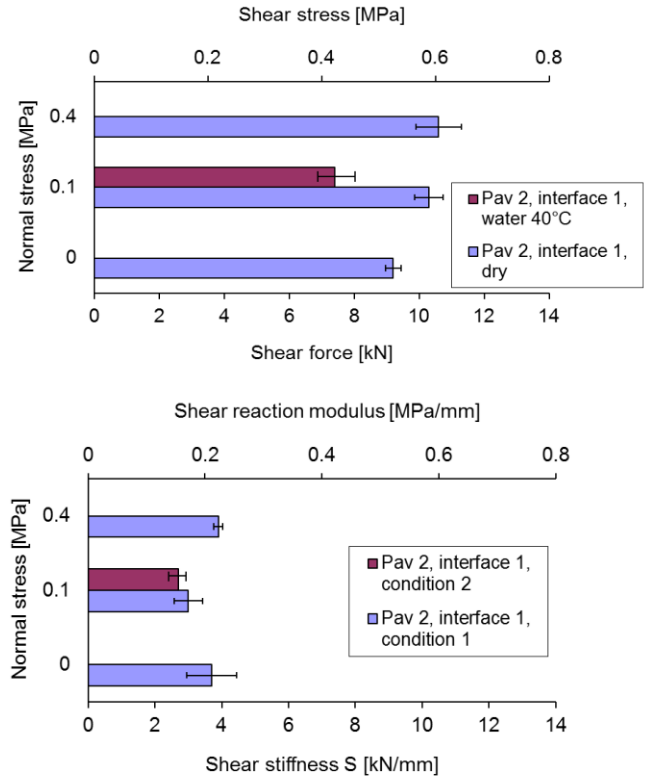

Fig. 11. Maximum Shear Force and Stiffness for Different Normal Stresses for Pavement 2, Interface 1, Conditions 1 and 2**.**

As visible in Fig. 11, pavement 2 reveals a ranking for the shear force (shear stress) from the lowest value 9.2 kN (1.2 MPa) without normal stress, to the highest shear forces (stresses) 10.3 kN (1.3 MPa) with a normal stress of 0.1 MPa and 10.6 kN (1.4 MPa) with normal stress of 0.4 MPa. Again, the shear force (stress) test results after water conditioning achieve the lowest shear force (shear stress) values with 7.4 kN resp. 1.0 MPa compared to pavement 1. As opposed to pavement 1, here the difference is statistically significant. Regarding the shear stiffness (shear reaction modulus) there is no difference for testing at normal stresses of σ_n = 0 MPa and σ_n = 0.4 MPa, while the shear stiffness at σ_n = 0.1 MPa is lower, although not statistically significant. In case of pavement 2, the difference between testing with and without water conditioning is significant, with lower values for testing of the water conditioned specimens.

For pavement 2, already for testing at 0.1 MPa, an increase in shear force (shear stress) compared to testing without normal stress

Table 5. LPDS Test Results at 20℃ for Pavements 1, 2 and 3, Interlayers 1 and 2 (Standard Deviation in Brackets).

Condition No.	F_{max} [kN]	τ_{max} [MPa]	w at F_{max} [mm]	S_{max} [kN/mm]	K_{max} [MPa/mm]
	Pavement 1, interface 1				
1	30.6 (2.07)	1.7 (0.12)	2.6 (0.26)	17.2 (2.04)	1.0 (0.13)
2	25.2 (2.29)	1.4 (0.12)	2.6 (0.36)	18.3 (1.87)	1.0 (0.13)
3	22.8 (1.34)	1.3 (0.07)	2.2 (0.29)	16.0 (2.44)	1.0 (0.16)
4	25.7 (0.96)	1.5 (0.05)	2.4 (0.27)	16.7 (3.27)	0.9 (0.15)
	Pavement 1, interface 2				
1	27.4 (3.91)	1.5 (0.22)	2.0 (0.21)	22.6 (6.69)	1.3 (0.4)
2	25.4 (0.52)	1.4 (0.64)	2.2 (0.19)	19.1 (2.36)	1.1 (0.11)
3	21.9 (2.04)	1.2 (0.12)	2.4 (0.25)	15.4 (0.20)	0.9 (0.14)
4	18.4 (4.02)	1.0 (0.23)	2.0 (0.17)	14.7 (1.38)	0.8 (0.09)
	Pavement 2, interface 1				
1	32.8 (3.19)	1.9 (0.18)	2.5 (0.10)	21.8 (3.65)	0.2 (0.21)
2	37.2 (2.95)	2.1 (0.17)	2.7 (0.23)	21.3 (3.29)	0.2 (0.20)
3	33.4 (3.77)	1.9 (0.21)	2.6 (0.42)	20.9 (1.07)	0.2 (0.08)
	Pavement 3, interface 1				
1	33.2 (4.99)	1.9 (0.23)	1.9 (0.16)	25.4 (3.62)	1.4 (0.21)
2	31.8 (5.91)	1.9 (0.33)	2.2 (0.22)	23.7 (4.44)	1.4 (0.26)
3	28.3 (9.31)	1.6 (0.63)	2.1 (0.50)	17.1 (3.86)	1.0 (0.25)
4	31.5 (7.35)	1.8 (0.42)	2.2 (0.33)	21.6 (7.00)	0.8 (0.08)
	Pavement 3, interface 2				
1	35.2 (4.5)	2.0 (0.25)	1.5 (0.24)	30.5 (1.93)	1.6 (0.13)
2	31.8 (4.02)	1.9 (0.22)	1.45 (0.23)	28.6 (5.4)	1.6 (0.30)
3	29.8 (5.65)	1.7 (0.32)	1.3 (0.18)	26.3 (4.43)	1.5 (0.29)
4	22.9 (4.03)	1.3 (0.23)	1.4 (0.37)	21.5 (6.99)	1.2 (0.45)

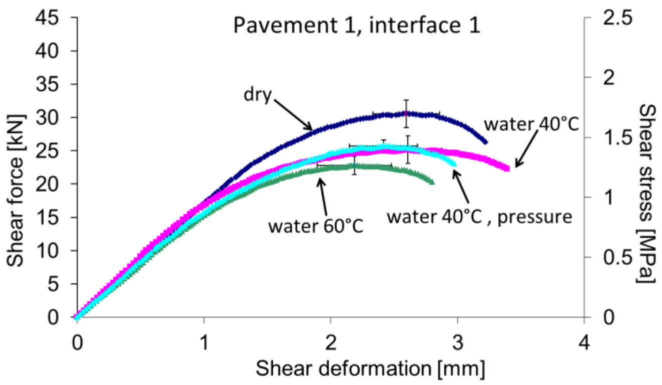

Fig. 12. Mean Shear Force (Stress) – Deformation Curves for LPDS Testing at 20℃ of Pavement 1, Interface 1.

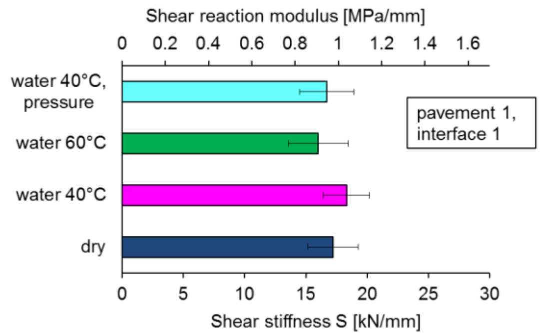

Fig. 13. Maximum Stiffness and Shear Reaction Modulus for Pavement 1, Interface 1, Conditions 1 to 4.

is visible, although not significant, while for testing at a normal stress of 0.4 MPa the increase is only marginal and lies within the standard deviation (see Fig. 11). Overall, the shear force (shear stress) results for interface 1 of pavements 1 and 2 are in a similar range and show no significant difference, a fact that might be attributed to their similar air void content. Similar findings are true for the shear stiffness (shear reaction modulus) and the shear deformation at maximum shear force.

Pavements 1, 2 and 3, interface 1 and 2: LPDS

All LPDS test results are shown in Table 5.

LPDS testing for pavement 1 was conducted for both interfaces and all test conditions according to Table 3. Pavement 2, which consisted of two layers only, was tested at conditions No. 1 to No. 3. LPDS testing for pavement 3 was conducted for both interfaces and all four test conditions.

According to Figs. 12 and 13 the shear force (stress) and the shear stiffness at the first interface of pavement 1 show a clear decline and therefore a weakening from condition No. 1 (without water) to condition No. 3 (water 60℃). When tested at condition 4 (water 40℃ and pressure), the shear force (stress) results are comparable to that of condition No. 2 while the shear stiffness achieves a value comparable to condition No. 3 (water at 60℃). The shear deformation at F_{max} does not seem to be influenced by the different conditioning situations.

At the second interface pavement 1 shows, apart from condition No. 2 (water 40℃), where the highest values for shear force (stress)

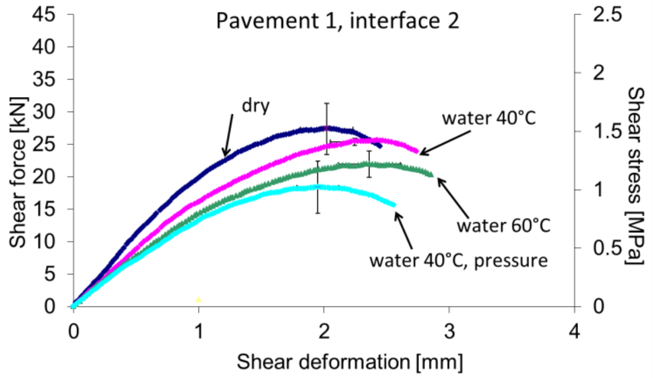

Fig. 14. Mean Shear Force (Stress) – Deformation Curves for LPDS Tasting at 20℃ of Pavement 1, Interface 2.

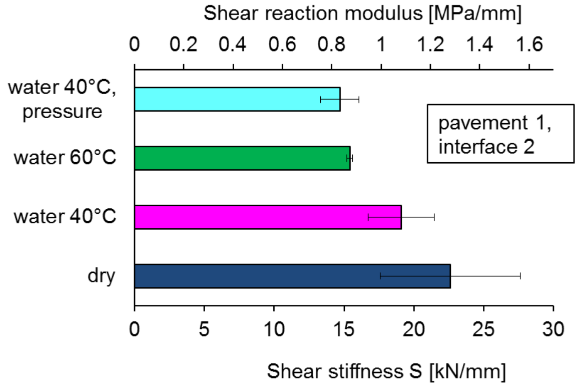

Fig. 15. Maximum Stiffness and Shear Reaction Modulus for Pavement 1, Interface 2, Conditions 1 to 4.

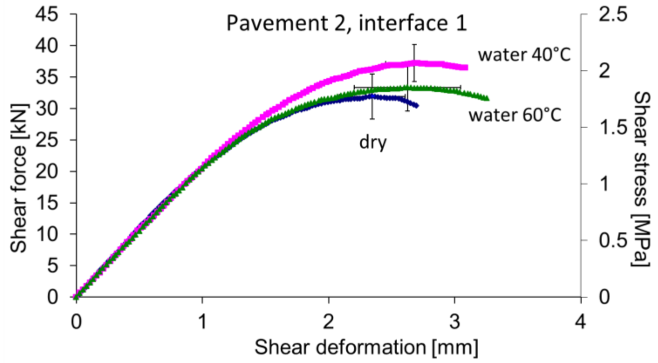

Fig. 16. Mean Shear Force (Stress) – Deformation Curves for LPDS Testing at 20℃ of Pavement 2, Interface 2.

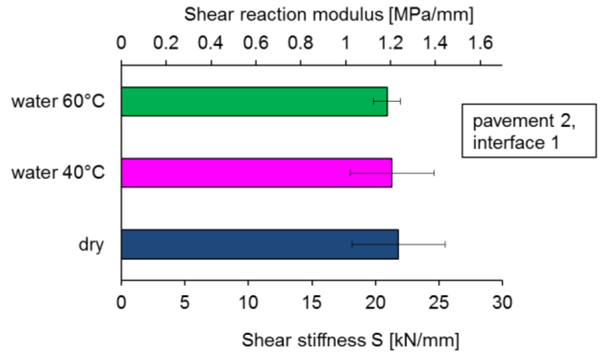

Fig. 17. Maximum Stiffness and Shear reaction Modulus for Pavement 2, Interface 1, Conditions 1 to 3.

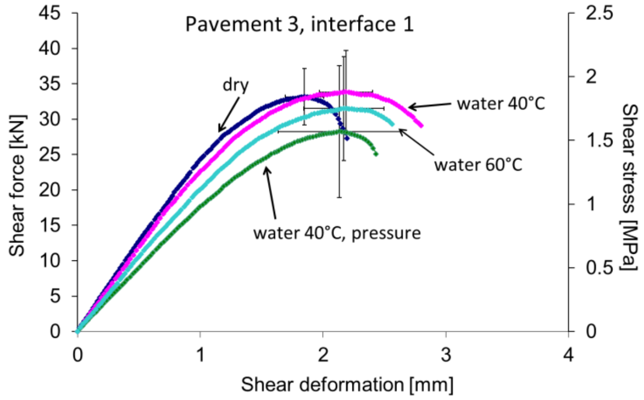

Fig. 18. Mean Shear Force (Stress) – Deformation Curves for LPDS Testing at 20℃ of Pavement 3, Interface 1.

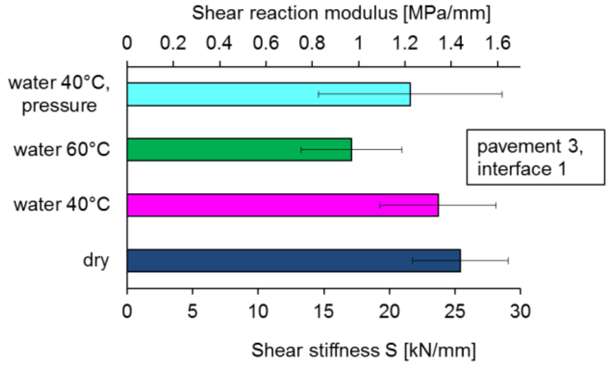

Fig. 19. Maximum Stiffness and Shear Reaction Modulus for Pavement 3, Interface 1, Conditions 1 to 4.

and shear stiffness can be found, a decrease in shear force (stress) and stiffness from condition No. 1 to condition No. 3 and No. 4. Again, the shear deformation at maximum shear stress is not really effected by the different conditioning procedures (see Figs. 14 and 15).

For pavement 2 (Figs. 16 and 17), which was only tested for conditions No. 1 to 3, water conditioning has nearly no impact on the shear stiffness and shear deformation, while the shear force (stress) increases from condition No. 1 (no water) to condition No. 2 (water 40℃) and for condition No. 3 is comparable to condition No. 1.

For the first interface of pavement 3 (see Figs. 18 and 19), the shear force (stress) and shear stiffness results are similar to those for the first interface of pavement 1. A clear decrease from condition No. 1 (no water) to condition No. 3 (water 60℃) can be found. Again, the results for condition No. 4 (water 40℃ and pressure) are similar to those of condition No. 2. Shear deformation values at F_{max} are between 1.9 mm and 2.2 mm.

For the second interface of pavement 3 (Figs. 20 and 21), the influence of water conditioning is leading to a decrease in both

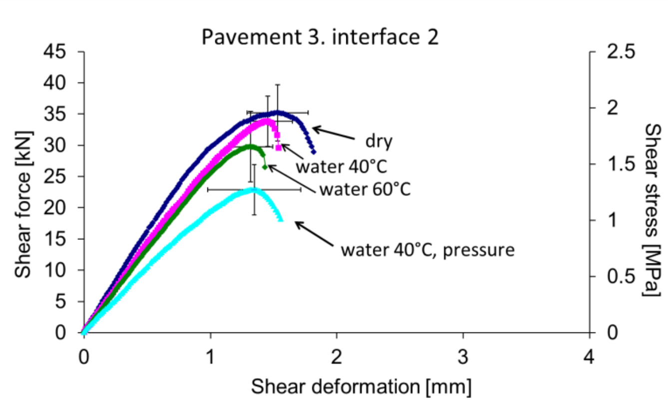

Fig. 20. Mean Shear Force (Stress) – Deformation Curves for LPDS Testing at 20℃ of Pavement 3, Interface 2.

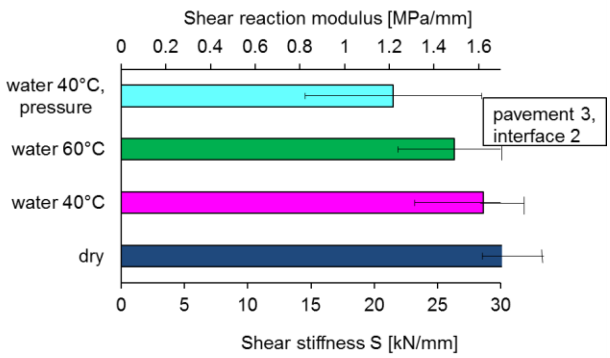

Fig. 21. Maximum Stiffness and Shear Reaction Modulus for Pavement 3, Interface 2, Conditions 1 to 4.

Table 6. Shear Box (Without Normal Stress) and LPDS Test Results for Pavements 1 and 2, Interlayer 1 (Standard Deviation in Brackets).

	Shear Stress [MPa] Pavement 1, Interface 1	Shear Stress [MPa] Pavement 2, Interface 1
Shear Box	1.2 (0. 19)	1.2 (0.13)
LPDS	1.7 (0.12)	1.9 (0.18)

shear force (stress) and shear stiffness from condition No. 1 (no water) to condition No. 4 (water 40℃ and pressure). For pavement 3 the decrease for condition No. 4 is found to be the biggest for all pavements which were tested at that condition.

Comparison Shear Box and LPDS, Pavements 1 and 2, Interface 1

For the first interface of pavements 1 and 2, a comparison between the maximum shear stress results from Shear Box without normal stress and LPSD is possible. However, one has to keep in mind that both tests were conducted at different deformation rates (Shear Box: 2.5 mm/min, LPDS: 50 mm/min) - a fact that will definitely have an influence on the magnitude of the maximum shear stress. The mean values of the maximum shear stress for both test methods are compared in Table 6.

The comparison between the maximum shear stress determined with the Shear Box and with LPDS shows that the maximum shear stress achieved from LPDS testing is for both pavements about 1.5 times higher than the one from Shear Box testing. This finding can be explained with the different deformation rates and other differences between both test methods, but it is not totally in agreement with the results from other researchers who found a value of 2 to 3 to convert maximum Shear Box stresses into maximum LPDS stresses [14]. A reason for this difference could be found in the different Shear Box equipment and in the difference of the investigated mixtures. While in this investigation the Shear Box from the Geotechnical Institute at ETH (Swiss Federal Institute of Technology) in Zurich was applied, Canestrari et al. used the Ancona Shear Testing Research and Analysing apparatus ASTRA [15]. There was also a difference in materials: The material investigated by Canestrari et al. consisted of two dense asphalt layers, while the specimens in the present research had always a surface layer with air void contents of more than 10 vol-%.

Conclusions

From the investigation it becomes clear that moisture generally has a negative influence on the interlayer shear bond of asphalt pavements. Apart from LPDS testing of pavement 2, all pavements in this investigation water conditioning shows a decrease in shear force and shear stiffness. The measured decrease is neither the same for all pavements and interfaces, nor for all test methods and conditioning cases. While the first interface of pavement 1 in the Shear Box shows only a slight decrease in shear force, when tested after water conditioning of 40℃, the LPDS result reveals a decrease after water conditioning of about 20%. A decrease of 20% in shear force can also be found in Shear Box testing for pavement 2, when LPDS testing even leads to an increase in shear force. When considering the water conditioning of 60℃, which was only done for LPDS testing, this conditioning mode proved even more severe for all pavements and interfaces which resulted in larger decrease in shear force of 15% to 25% and shear stiffness of 14% to 30%. This is also true for pavement 2.

Testing pavements 1 and 3 at 40℃ after short time water conditioning combined with pressure, produces interesting results. When the air void content in the upper layer is high (here: higher than 10 vol-%), condition No. 4 (40℃ short term water conditioning combined with pressure) has a similar influence as long-term water conditioning at 40℃ (Condition No. 2), while for normal air void contents in the upper layer (around 4 to 5 vol-%), condition No. 4 proves to be the most severe test condition regarding its influence on shear force and stiffness. This finding can be explained by the fact that the applied pressure is released through the air voids and therefore has a smaller influence on shear stress and shear stiffness than for denser upper layers. In order to achieve the same effect as for pavements with dense upper layers, it is important to seal the cores during pressure conditioning. Contrary to the findings from earlier research [7], when it was found that the reduction in shear force caused by long term water storage of 75h at 40℃ was equal to short term water storage at 40℃ of 8h combined with a pressure of 0.05 MPa, in this investigation, the combined moisture-pressure treatment of pavements with dense upper layers had a more severe impact on the decrease of shear stress and stiffness. Nevertheless, to accommodate all pavement types 72h moisture conditioning at 60℃ can be recommended.

In summary this investigation showed the following findings:

1) Water conditioning at 40℃ or 60℃ generally has a negative effect on the interlayer shear bond leading to decreases in shear force and shear stiffness since it penetrates into the structure weakening the bond between the layers.
2) 72h water conditioning at 40℃ reduces interlayer shear strength by 2% to 20%.
3) 72h water conditioning at 60℃ is more severe, reducing strength by 15% to 25% and stiffness by 14% to 30%.
4) For upper layer with air void contents of ca, 5 vol-% the largest strength and stiffness reduction up to more than 30% was received when 5h water conditioned at 40℃ with pressure of 0.05 MPa.
5) For pavements with upper layer air void contents >10 vol-%, 5h water conditioning combined with a pressure of 0.05 MPa is less serve since pressure is released through the air voids. For these pavements this treatment has a similar effect on shear force and stiffness as 72 h water conditioning at 40℃. In order to achieve an influence comparable to the pavements with dense upper layers the cores need to be sealed during the conditioning.
6) In order to avoid cumbersome specimen preparation and difficulties with variable air void contents, it is recommended to test the influence of water conditioning on the interlayer shear properties by 72 h water storage at 60℃.
7) A comparison between this specific ETH Shear Box and LPDS testing at different deformation rates (2.5 mm/min and 50 mm/min) gives a factor of 1.5 to convert maximum shear stress from Shear Box testing into maximum shear stress from LPDS testing.

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