Assessment of Interlayer Bonding Properties with Dynamic Testing

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ABSTRACT

Although static interlayer bond testing has been established for quality control during recent years its practical relevance for material related bonding properties has been questioned. In the wake of this discussion several presumably more realistic cyclic testing procedures have been proposed. The Germany testing device and a procedure developed at the University of Dresden even found entrance into the European standardization. Although a guideline for its application has been defined and the device has been made commercially available for a couple of years the procedure has only been validated on specific German asphalt mixtures. This paper presents an investigation of the German dynamic interlayer bond testing for a variety of asphalt pavements such as mastic, stone mastic and porous asphalt. The authors show the differences for these pavement types revealing the need for a modification of the existing testing procedure. The paper further discusses results from static and dynamic interlayer bond testing.

Keywords interlayer bond, dynamic method, German device, material related bond property.

1. INTRODUCTION

Lately, more and more interlayer bond testing devices or modifications of devices have been proposed [1], [2]. One of the first developments for a standard shear testing device came from Germany, where University of Karlsruhe proposed a shear apparatus which could be installed into a universal testing machine [3]. Although, this device was only applicable for static testing without applying any normal force, this experimental setup was modified and adopted by various other countries. Hence, it became one of the most important devices for interlayer bond testing. However, not only interlayer bonding properties at failure in the static test, but also during service are important for predicting the service life of an infrastructure. In this context several dynamic testing devices have been proposed [4], [5], [6]. The German testing device and procedure developed at University of Dresden [7] even found entrance into the European standards [8] and has been commercially available for a couple of years. Despite this fact, the device has mainly been used in Germany and the experience also in comparison to the static equipment is limited [7], [9], [10]. The objective of the present study was an investigation of dynamic interlayer bond testing with the German method for a variety of asphalt pavements such as mastic asphalt MA and stone mastic asphalt SMA and porous asphalt PA. The differences for the pavement types is shown revealing the need for a modification of the testing procedure. The paper further discusses results from both static and dynamic interlayer bond testing.

2. STATIC TESTING DEVICE

Static interlayer bond testing was performed with the Layer-Parallel Direct Shear (LPDS) test device for cylindrical specimens, a modified version of the equipment developed in Germany by [3], [11], [12]. The application of a normal force is not possible. One part of each specimen (up to the shear plane to be tested) is placed on a circular u-bearing and held with a well-defined pressure by a semi-circular pneumatic clamp. The other part, the core head remains unsuspended. Shear load is induced to the core head by a semi-circular shear yoke with a deformation rate of 50.8mm/min, thus producing fracture within the pre-defined shear plane of 2mm width. The exact testing procedure is also described in Swiss Standard [13].The interlayer bond is determined for Ø150mm cores at a temperature of 20°C. For research purposes and in order to compare static and dynamic interlayer bond results other temperatures were also tested.

3. DYNAMIC TESTING DEVICE

Cyclic interlayer bond testing was carried out with the dynamic shear bond testing device developed at University of Dresden [7]. For testing specimens with diameters of 100mm are fixed into half-shells using 2-component epoxy glue. The lower half-shells are mounted on aluminium supports. One of these supports is fixed horizontally and the other mounted vertically movable. The shear force is induced by the vertically movable support, while the horizontally movable support enables the application of normal force and allows adjusting the distance between the lower half-shells. The shear force is applied by the hydraulic cylinder of the servo-hydraulic testing machine. The applied load is dynamically displacement-controlled using a sinusoidal signal (tension-compression). The displacement amplitude is temperature dependent and aimed to stay within the linear viscoelastic range. The shear displacement amplitudes at different temperatures are: 0.03mm (-10°C), 0.07mm (10°C), 0.11mm (30°C) and 0.15mm (50°C). There are two transducers measuring the shear displacement and two transducers measuring the normal displacement of the specimen. A data logging system records loads and displacements during the test. For temperature control, the device is placed in a temperature chamber. The testing sequence in Figure 1 shows testing cycles for different temperatures, frequencies and normal loads. For each temperature with corresponding displacement amplitude, five normal forces and five frequencies are applied. Frequencies of 0.1, 1, 5 and 10 Hz and normal loads of 0, 0.3, 0.6 and 0.9MPa are chosen. At the end of each test, for control purposes, the tests at the last temperature are repeated.

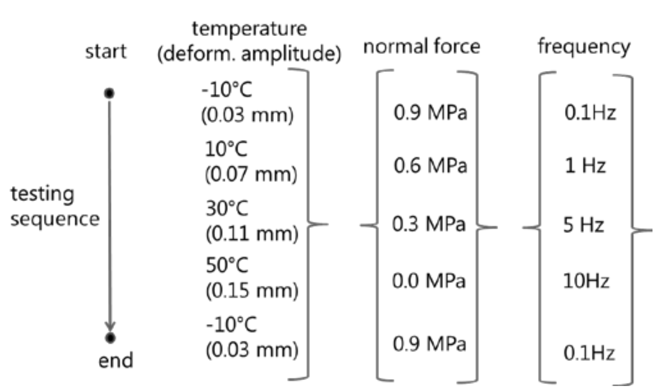


FIGURE 1 Testing Sequence

4. MATERIALS AND TESTING

Three material combinations consisting of double layered specimens with different surface course materials according Table 1 were chosen for testing. The specimens were drilled and cut from multi-layered slabs taken from Swiss expressways. Table 1 shows the mixture types, the bitumen and their air void content. Between the SMA and the AC layer a cationic emulsion with an application rate of 200g/mm^2 and a residual bitumen content of 60 M-% had been applied as tack coat. No tack coat was used between the MA layers. In case of the porous asphalt, a stress absorbing membrane interlayer SAMI had been put on top of asphalt concrete layer. The core diameter depended on the testing device being 150mm for the static and 100mm for the dynamic testing device. Interlayer bond between the first and second layer was determined either by static or dynamic testing. For SMA/AC static testing was done at -10, 10, 20 and 30°C, MA/MA and PA/AC were tested at 20°C and 40°C.

TABLE 1 Investigated Material Combinations

	SMA/AC		**MA/MA**		**PA/AC**	
Layer No.	**1**	**2**	**1**	**2**	**1**	**2**
Mix type	SMA 11	AC 22	MA 11	MA 16	PA 11	AC 22
Binder Content [%]	3.2	3.2	7.8	6.8	22.6	3.7
Air void Content [%]	5.8	4.8	1.2	1.3	4.3	5.6

Testing delivers shear forces from which shear stress τ and shear stiffness K were calculated using the following equations for static and dynamic testing according [8]:

$$\tau = F/A \qquad \text{Eq. (1)}$$

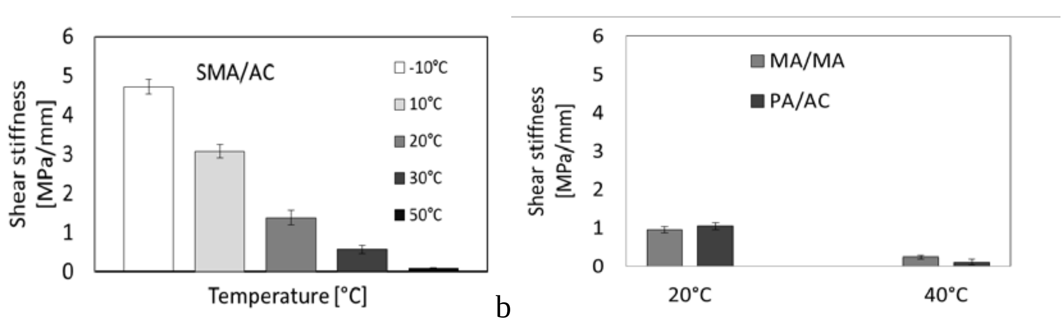
with F: shear force for static or shear force amplitude [N] for dynamic test and A: sheared area [mm^2]

$$K = \tau / s \qquad \text{Eq. (2)}$$

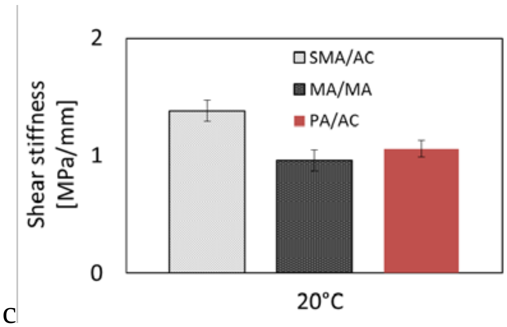
with s: displacement at peak stress for static or amplitude of relative displacement [mm] for dynamic test.

5. RESULTS OF STATIC TESTING

Figures 2a-c depict the shear stiffness for all three material combinations calculated with Eqs. (1, 2). Every column represents the average of 5 to 7 specimens.



a b



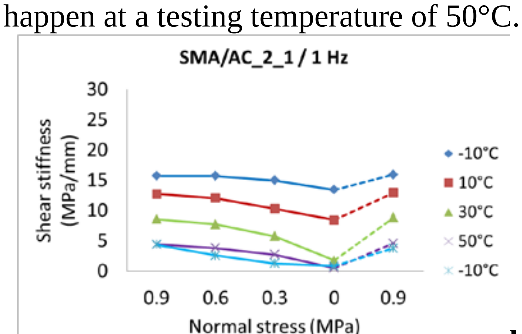
c

FIGURE 2 Shear Stiffness at different Temperatures: a) SMA/AC, b) MA/MA and PA/AC c) SMA/AC, MA/MA and PA/AC at 20°C

From the results it becomes clear that stiffness is highly dependent on the temperature decreasing from 5 MPa at a testing temperature of -10°C to 0.25 MPa at a testing temperature of 50°C for SMA/AC. A comparison between the three materials at 20°C shows very similar shear stiffness around 1 MPa/mm for the MA/MA and the PA/AC while the shear stiffness for the SMA/AC with 1.5 MPa/mm is slightly higher.

6. RESULTS OF DYNAMIC TESTING

Since dynamic testing is done at different frequencies using different normal loads, the relationship with temperature cannot be shown in a simple diagram. As an example Figure 3 depicts, the shear stiffness at 1Hz for different normal stresses and temperatures for two different specimens of SMA/AC, MA/MA and PA/AC. It has to be noted that testing with the prescribed deformation amplitudes of 0.03mm, 0.07mm, 0.11mm and 0.15mm was not possible. Therefore, the deformation had to be reduced to 1/3 of these amplitudes. From the results follows that, similar to static testing, shear stiffness decreases with increasing temperature, but stiffness values are considerably lower than for static testing. This can be explained by the fact that dynamic testing is conducted in the elastic range where no damage should occur. Further, stiffness increases with increasing normal stress, confirming findings by different researcher when applying normal loads for static testing (Raab et al, 2009, Ferrotti et al., 2015). From the comparison of the two specimens of the same material the big scattering between 17% and 50% becomes obvious. This makes statements concerning the ranking of the investigated materials quite difficult. As far as this investigation is concerned, MA/MA seems to receive the highest stiffness values, while PA/AC has the lowest ones. The difference between the first and the last shear stiffness test result at -10°C can be contributed to a damage of the specimen which often appears to happen at a testing temperature of 50°C.



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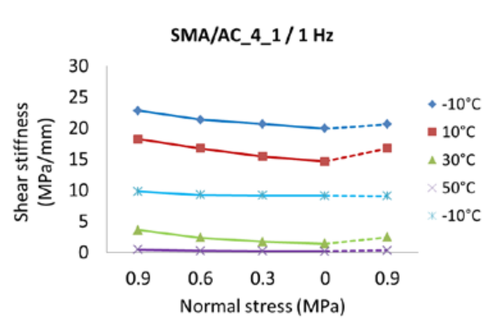

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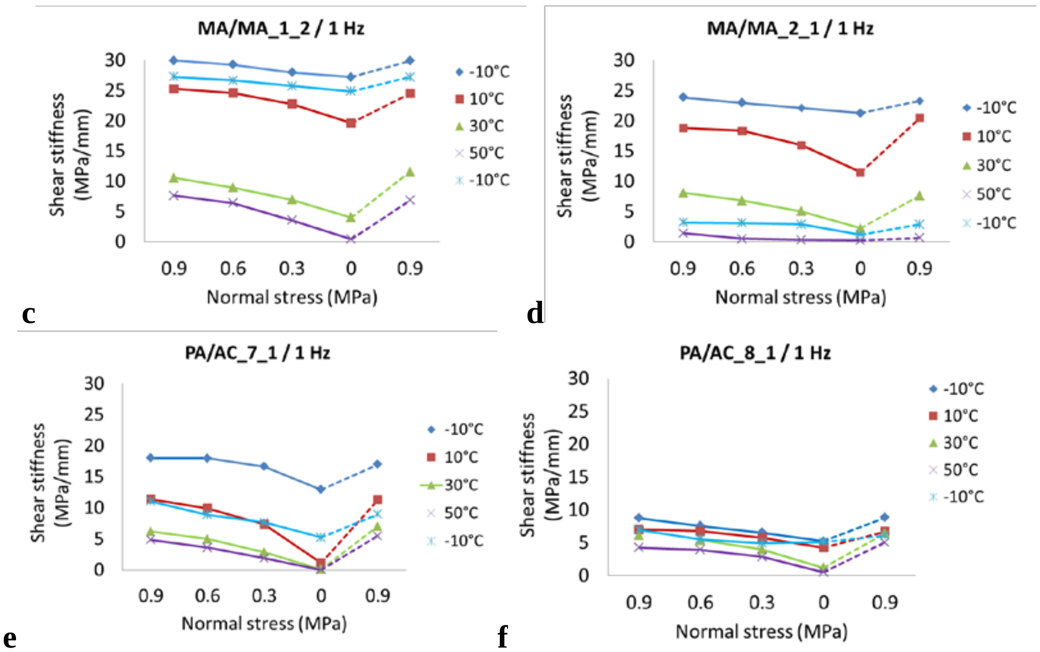

FIGURE 3 Shear Stiffness at 1 Hz for different Normal Loads and Temperatures: a) and b) SMA/AC, c) and d) MA/MA, e) and f) PA/AC

Dynamic testing allows applying the time (frequency) and temperature relationship which enables to construct the so-called Master curve for shear stiffness K with the help of the time-temperature-superposition principal.

Figure 4 shows such a shear stiffness Master curve for MA/MA, different normal stresses and a reference temperature of 20°C. Again, the dependency on normal stress is obvious.

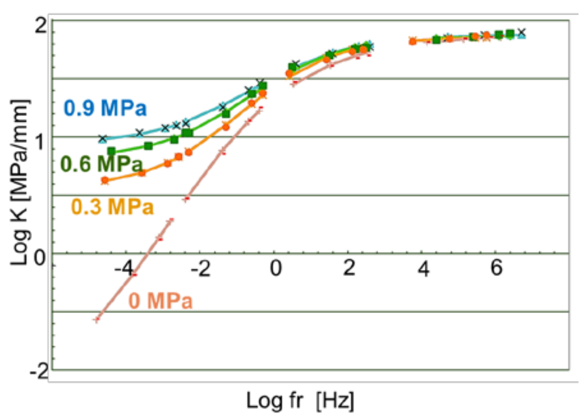

FIGURE 4 Master Curve of Shear Stiffness for MA/MA for different Normal Stresses and a Reference Temperature of 20°C

7. DISCUSSION

When comparing the results from static and dynamic testing, at first glance, the results seem to be similar: increasing interlayer shear stiffness corresponds with decreasing testing temperature. At second glance, not only the received values but also the purpose of testing appears to be different. While static testing determines interlayer bond failure, dynamic testing offers a complex evaluation of interlayer bond properties which can be used for the evaluation of pavements' service life. From the dynamic results, master curves can be retrieved which enable to predict the shear stiffness for all combinations of temperature, strains and stresses of interest, based on a limited amount of testing. Further, the results from dynamic testing are not only valuable for quality control but can be used for various purposes, such as modelling and design. However, a lot of open questions regarding the proposed test method and testing sequence prescribed in the German procedure still remain: The shear deformation amplitudes seem to be very high and it is not clear if they are for all test configurations still in the elastic range. In this research they had to be reduced to a third of their original values. It further appears likely that these amplitudes are material dependent and that pre-testing should be mandatory when testing a new material combination or tack coat.

For some materials testing produced high differences between first and last shear stiffness result at -10°C. This shows that the specimens might have been damaged during testing, raising the question for revising the proposed test temperature. Especially the temperature of 50°C seems to be critical. Last, not least dynamic testing proved to be cumbersome and the gluing of specimens offered several problems. For example it was extremely difficult to handle the gap width of 1mm and to install the glued specimen into the testing device. From the experience of this research it appears possible that such impairments might also have a direct influence on the achieved results.

8. CONCLUSIONS

The conclusions obtained from this study are as follows:

Shear stress and shear stiffness are clearly dependent on temperature leading for static and dynamic shear test methods to increasing values with decreasing temperature. Although static and dynamic testing show similar trends regarding the dependency of shear stiffness, values are different between both test methods for the same testing conditions (temperature and normal load). For static and dynamic testing a decrease of stiffness between 98% and 96% was found when comparing the stiffness values of SMA/AC at temperatures of -10°C and 50°C.

Static and dynamic test do not have the same goals and output: Static testing investigates interlayer bond properties at failure and is considered for quality assessment, while dynamic testing aims at the interlayer bond properties during the service life of a pavement.

Although results from dynamic testing shown in this paper seem promising, the investigation clearly shows that the testing method still needs further evaluation and the testing procedure has to be modified before it can be adopted for standardization. In this context the proposed deformation amplitudes and test temperatures have to be further investigated and probably modified according to the tested material combination. Modifications concerning the gluing and installing procedure appear to be necessary and the number of test specimens per material has to be increased. Here, the results from the investigation reveal quite a big scattering up to 50% when testing different specimens from the same material combination which makes statements on the ranking of different material combinations and between static and dynamic testing difficult.

Further, interlaboratory studies on testing devices and testing procedures including specimen preparation will be needed for comparison and harmonization of testing devices and methods.

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