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Interlaboratory test to characterize the cyclic behavior of bituminous interlayers: an overview of testing equipment and protocols

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Abstract. The performance assessment of multi-layered pavements strongly depends on the mechanical behavior of the interface between bituminous layers. So far, comprehensive studies have been carried out mainly using quasi-static laboratory tests focusing on the interlayer shear strength at failure. However, it is generally recognized that cyclic shear testing will lead to the determination of parameters which are more closely linked to the performance of pavements under traffic loading than the quasi-static shear tests. This paper outlines the research work that has been carried out within the Task Group 3 “Pavement multilayer system” of the RILEM TC 272-PIM. The activities focused on cyclic shear testing of interfaces in bituminous pavements involve an interlaboratory test with nine participating laboratories. The interface behavior was investigated through both direct shear and torque tests on double-layered specimens extracted from lab compacted slabs prepared by one of the laboratories.
The different testing equipment and protocols used by the participating laboratories are presented, highlighting the variety of geometries, loading modes, and testing parameters.

Keywords: interlayer bonding, bituminous interlayer, cyclic loading, stiffness, damage accumulation, interlaboratory test.

1 Introduction

Traffic loading on pavement structures induces horizontal stresses that may become critical when poor interlayer bonding conditions exist, leading to premature pavement failure.

Static shear testing devices have been largely applied to analyze the interlayer shear properties, mainly expressed in terms of the interlayer shear strength (ISS) [1]. Since traffic loads applied to the pavement are cyclic in nature, cyclic interlayer testing should lead to more realistic predictions of pavement performance. In particular, it would be helpful to understand the interlayer behavior in terms of cyclic shear stiffness for better predicting the bearing capacity of multi-layered pavements. Moreover, the fatigue shear resistance at the interface should be investigated to establish, for a given pavement structure, which is predominant between bottom-up cracking (depending on tensile stress/strain) and slippage failure (strictly linked to the bonding between pavement layers).

In order to fill this gap, an interlaboratory test on "Cyclic Interlayer Shear Testing" was promoted by Task Group 3 "Pavement Multilayer System" of RILEM Technical Committee 272-PIM "Phase and Inter-phase behavior of bituminous Materials". Within the RILEM interlaboratory test, different cyclic shear testing devices currently available were used by the participating laboratories with the aim of identifying appropriate testing protocols and meaningful parameters. Several tests were performed on double-layered specimens extracted from lab compacted slabs prepared by one of the laboratories using a single bituminous mixture [2]. The objective of this paper is to present different testing devices and protocols used by the participating laboratories for performing cyclic interface testing.

2 Testing equipment and protocols of participating laboratories

The Cyclic-Ancona Shear Testing Research and Analysis (ASTRA) device (Fig. 1a) was used at Polytechnic University of Marche (UNIVPM). It consists of two half-boxes separated by an adjustable gap [2]. One half-box moves vertically allowing the application of a vertical load (parallel to the interface). The other half-box can slide horizontally (perpendicular to the interface) allowing shear dilatancy. The device also allows applying a prefixed normal load (perpendicular to the interface), by means of a pneumatic actuator. Cyclic-ASTRA tests were carried out in haversine stress control mode at 10 °C and 20 °C with a frequency of 5 Hz, without the application of a normal load. Four stress amplitudes were used, based on the average interlayer shear strength (ISS) of the double-layered specimens measured with the static test. The ratio between the applied amplitudes and the measured ISS were 0.29, 0.37, 0.44 and 0.51. For each cycle, the data acquisition system recorded the shear load (used to calculate the shear stress τ_0) and the relative interface displacement u_0. Results show typical three stages evolution of the permanent displacement at the layer interface as a function of the number of cycles until failure.

The Advanced Shear Tester (AST) device (Fig. 1b), was used both at Gdansk University of Technology (GUT) and at Road and Bridge Research Institute (IBDiM). It consists primarily of two parts, stationary holder and moving collar, with a variable gap size between them [3]. AST device can apply a normal confining stiffness to the interface by means of four die springs. GUT carried out cyclic AST tests at 20 °C by adopting a gap of 2 mm; the loading cycle was characterized by a minimum (50 kPa) and maximum shear stress (330 kPa and 450 kPa) set as 20% of the Leutner interlayer shear strength (ISS). Each cycle consisted of 0.05 s of loading time, 0.05 s of unloading time and 0.1 s of rest time. Several parameters were obtained as a function of the cycle number such as permanent strain, shear stiffness (permanent and resilient), total accumulated dissipated energy (from hysteresis loops) and equivalent energy ratio. IBDiM carried out Cyclic AST tests with a gap of 5 mm at 13 °C, both without and with initial normal stress (400 kPa). The testing protocol included a frequency sweep (1, 2, 5, 10 Hz) in sinusoidal control stress mode followed by a haversine fatigue test at 10 Hz.

The Modified Advanced Shear Tester (MAST) device (Fig. 1c) was used at North Carolina State University (NCSU). It is composed of a fixed side platen and a movable side platen separated by a gap of 8 mm. The movable side platen is free to move vertically (parallel to the interface) as well as horizontally (perpendicular to the interface); MAST device allows also the application of a normal confining stiffness to the specimen by means of a bolt and spring system [4]. Cyclic MAST tests were carried out in haversine displacement control at a temperature of 20 °C, with a frequency of 5 Hz and without applying any normal (confining) stress at the interface. Displacement and shear stress amplitudes, u_0 and τ_0 respectively, were collected during the test in order to calculate the interlayer shear stiffness $K = \tau_0/u_0$. Typical results of constant displacement amplitude cyclic (CDAC) tests consider as output the number of cycles to failure (N_f) associated with the 50% reduction of interlayer shear stiffness.

The Cyclic Compressed Shear Bond (CCSB) device was used by Empa, in collaboration with the University of Dresden. Double-layered cylindrical specimens are glued into half-shells mounted on aluminum supports (Fig. 1d). The shear load is dynamically displacement-controlled using a sinusoidal signal and applied by a vertically movable support, while the horizontally movable support enables the application of normal load. Different shear displacement amplitudes were selected at different temperatures (0.03 mm @-10 °C, 0.07 mm @10 °C, 0.11 mm @30 °C and 0.15 mm @50 °C) in order to run the tests within the linear viscoelastic range. For each temperature with corresponding displacement amplitude, 4 normal loads (0.0, 0.3, 0.6 and 0.9 MPa) and 5 frequencies (0.1, 0.3, 1, 3 and 10 Hz) were chosen.

The Repeated Impulse Leutner (RIL) device was designed at the University of Bologna and enables the evaluation of shear strengths under cyclic shear loading when subject also to a normal load. The aim of the proposed test is to evaluate the shear strength of the interlayer under cyclic shear loading when subject also to a normal load. The device consists of a traditional Leutner device fixed on a frame equipped with a pneumatic piston able to carry out a constant and normal pressure to the upper face of the double-layered cylindrical specimen (Fig. 1e). RIL device applied cyclic shear load according to a haversine and repeated loading pulse, with the peak value fixed at 250 kPa, a pulse repetition period of 1500 ms and a rise time of 130 ms.

The University of Minho developed the Dynamic Interlayer Shear Testing (DIST) device to assess the interlayer bond of asphalt pavements by applying monotonic or cyclic shear loads on double-layered cylindrical specimens. The device is composed of two circular crowns to fix each part of the specimen (Fig. 1f) and, being equipped with two servo-hydraulic actuators, allows applying also normal forces at the interface. The interlayer shear behavior was evaluated at 20 °C, without normal load, in three modes:

1) frequency sweep; 2) displacement sweep; 3) fatigue. Frequency sweep tests were carried out by applying a cyclic shear displacement of 0.1 mm at frequencies from 0.1 to 2 Hz. Displacement sweep tests were carried out at 1 Hz applying cyclic displacements from 0.05 to 0.30 mm. The number of cycles was very low to avoid damaging the specimen. Fatigue tests were carried out at 5 Hz applying a cyclic displacement of 0.05, 0.10 and 0.15 mm

The Interlayer Shear-Torque (IST) device (Fig. 1g) was used to perform fatigue tests at University of Limoges by means of a servo-hydraulic testing equipment [5]. IST fatigue tests were carried out in controlled stress mode at a frequency of 10 Hz and a temperature of 20 °C. A sinusoidal torque and a constant axial compression load N of 0.05 kN were applied to the double-layered cylindrical specimen glued with an epoxy resin to the loading plates. IST fatigue test returns, for each level of torque amplitude, a dataset including the evolution of torque, axial load, torsional rotation angle and phase angle as a function of the number of cycles. The interlayer behavior was characterized through the complex shear modulus G^*. The evolution of the norm of the complex shear modulus $|G^*|$ as a function of the number of loading cycles was analyzed at the end of each IST fatigue test. Classical 50% modulus reduction criterion was adopted to determine the number of cycles to failure (N_f) associated with the corresponding shear stress amplitude

The 2T3C Hollow Cylinder Apparatus (2T3C HCA) was developed at the University of Lyon/ENTPE to study the mechanical behavior of pavement interlayers [6] (Fig. 1h). Torsion and tension/compression are applied independently to a hollow cylinder specimen placed inside a thermal chamber (from -20 °C to 60 °C). The dimensions of the double-layered hollow cylinder specimen were 74 mm total height, 172 mm external diameter and 122 mm internal diameter (thickness of 25 mm). Two pairs of non-contact sensors measure the vertical displacement and the displacement due to the rotation between the top and the bottom of the specimen. 3D Digital Image Correlation was used to obtain local displacements on the surface of the specimen. The corresponding strain tensor components ε_{zz}, $\varepsilon_{\theta z}$ in both layers. The displacement gaps at the interface in the axial direction Δu_z and in rotation Δu_θ were determined by means of a specific analysis. Furthermore, a special acquisition system allowed to calculate the associated vertical stresses σ_{zz} and shear stresses $\tau_{\theta z}$. Cyclic sinusoidal loadings at small strain amplitudes were applied at four temperatures (10, 20, 30, 40 °C) and, for each temperature, at four frequencies (0.01, 0.03, 0.1, 0.3 Hz). For each couple of temperature and frequency, several mechanical parameters were obtained and, among others, the complex interface shear modulus $K_{\theta z}^*$.

3 Preliminary results

The cyclic testing procedures applied by the participating laboratories focused on stiffness and fatigue resistance (Figure 2) of the double-layered specimens. Stiffness results showed a time and temperature dependent behavior and allowed the construction of master curves. Fatigue results showed that the interlayer behavior can be analyzed following the same approaches normally adopted for bituminous mixtures (i.e. stiffness reduction with increasing loading cycles). In all cases, the gap imposed by the testing device had a relevant influence on the results.

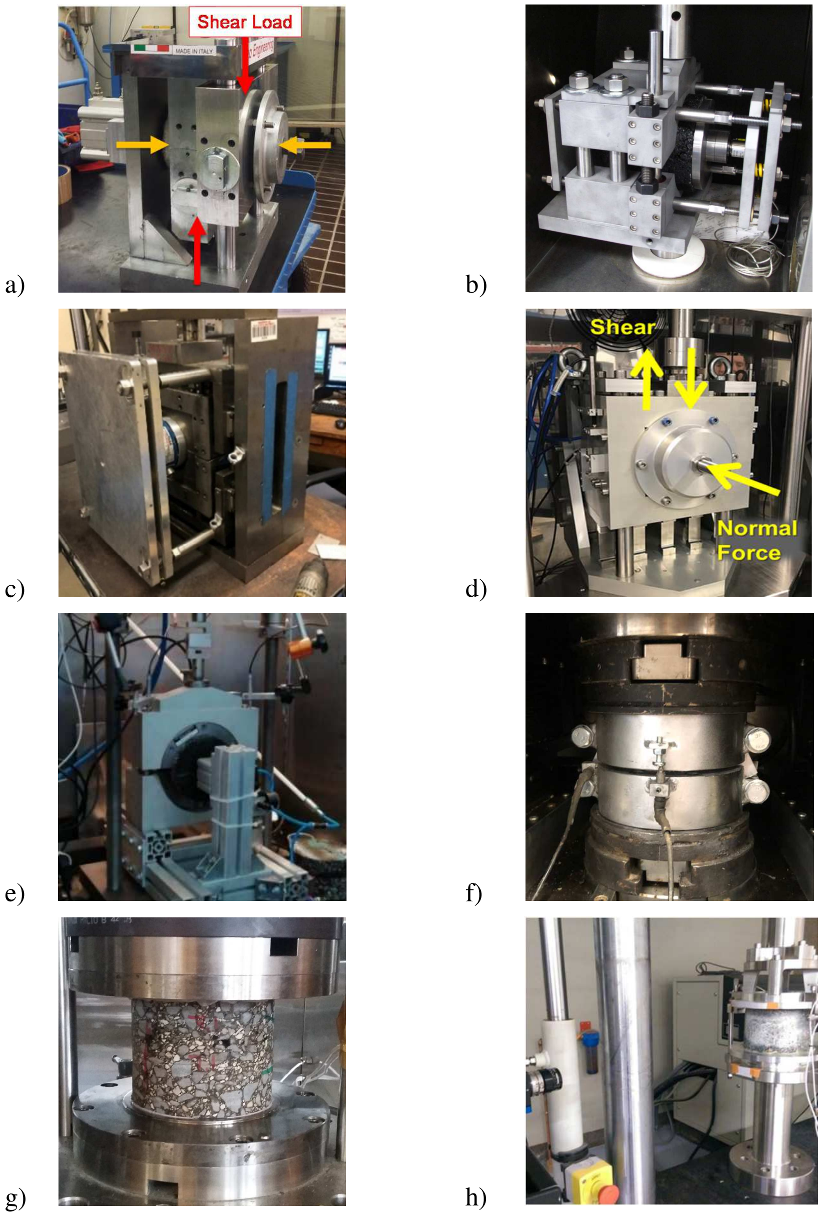

Fig. 1 Laboratory testing equipment used by the participating laboratories: a) Cyclic-ASTRA; b) AST; c) MAST; d) CCSB; e) RIL; f) DIST; g) IST; h) 2T3C HCA

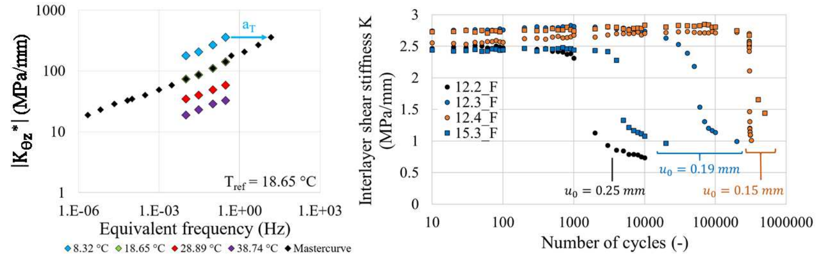

Fig. 2 Stiffness master curves (left); stiffness evolution in fatigue tests with different displacement amplitudes u_0 (right).

4 Conclusions

Nine laboratories applied their own different cyclic testing equipment and protocols to evaluate interlayer shear stiffness and/or the fatigue resistance of double-layered asphalt specimens. Very different geometries, loading modes, and testing parameters were compared. Although these differences did not allow the direct comparison of the measurements, results clearly showed that the influence of testing frequency and temperature can be analyzed using the time-temperature superposition principle typically adopted for bituminous mixtures. Moreover, some key issues were identified for improving the testing standardization such as the specimen clamping (glued, not glued), the interlayer gap, the testing mode (stress- or strain-controlled) and the applied loading amplitude (either stress or strain).

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