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Pavement interface damage behavior in tension monotonic loading

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HIGHLIGHTS

- Determine the asphalt concrete mechanical properties form an optical method analysis.
- Identify the interphase thickness in relation with the roughness parameter.
- Identify the interface damage behavior in the tensile monotonic loading.
- Characterize the interface parameter through homogenization approach.

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ABSTRACT

The degradation of the bituminous pavement structures is due to the several external loads (climatic conditions and traffic) and the weak bond between layers. Thus, it is important to take into account the interface behavior in the pavement computational design which is never considered actually. In order to provide reliability and efficiency of the design methods, the interface characterization study is required. In this study, a monotonic tensile test was performed for better understanding of the global and local structure behavior by using the Digital Images Correlation (DIC) analysis. The obtained results allow us to characterize the constitutive law of interface and mechanical parameters such as: stiffness, damage evolution, and release rate energy.

1. Introduction

The existing conventional design method for multilayered asphalt pavements considers the bond between two layers, called *interface*, as perfectly coated, semi-coated or slipped [1]. The recent researches show that the interface is a crucial component in the bituminous pavement structure behavior. Therefore, the perfect bond allows reducing the damage and cracks between pavement layers. In the practice, the recurrent distresses (cracks, alligator cracks, potholes, depressions, etc.) associated with de-bonding between layers are observed despite the respect of the bitumen emulsion implementation conditions in the tack coat. These degradations are generally caused by the traffic loading (shear and/or normal stress) and the environmental conditions effects [2,3]. In the addition, the experimental studies [4] conclude than the interfacial strength between pavement layers depends on several variables such as: the type of aggregate, materials content, surface properties (roughness, cleanness, durst, air void, . . .) [5,6], tack coat type, dosage [7–11], and the environmental condition (water, temperature, . . .) [12,13].

Furthermore, in this kind of structures, the interface modeling behavior is few treated in the literature [14,15] since it's ignored in the current design methods. A theoretical study [16] showed the impact of the bond between two layers. However, the transition from the case of perfect bonding condition to a sliding reduces significantly the lifetime of a road structure.

As noted in the previous, the interface behavior characterization is important and must consider in the design methods. In the fact, it is imperative firstly to understand and to identify the behavior of the Intermediate Transition Zone (ITZ) called *interphase* [17] located between layers separated by the *interface*. This delicate point which is not approached in the pavement structures, on the contrary, is studied in other fields like as composite materials

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[18,19] masonry [20,21] and concrete [22,23]. The research in these fields allows one to identify the interphase thickness (various from nano to macro scale), the interface and interphase mechanical parameters (constitutive law, Young's modulus, friction coefficient, ...).

In this paper, the interface behavior in the asphalt pavement structure is treated with taking into account the material behavior at the macroscopic scale. This material usually governed by a viscoelastic behavior was widely studied in the literature [24,25]. The experimental characterization is performed by using the optical methods [26–30] . In the first section, the materials and methods used in the present study were presented. In the second section, the global and local analysis behavior of the bi-layered structure under a tensile loading (mode I) are given. The focus on the optimal subset size choice is discussed in order to identify the mechanical properties. In the last section, a homogenization method is proposed to characterize experimentally the interface parameters from a representative elementary volume (REV) of bituminous materials.

2. Background

In the literature, several experimental devices and testing procedures are proposed in order to analyze the mechanical behavior of the interface from monotonous or cyclic loading [5]. Among these experimental techniques UTEP Pull-Off Device (UPOD) [31], Wedge-Splitting Test (WST) [32], Louisiana Tack Coat Quality Tester (LTCQT) [33], ATacker Test [34] or Interface Bond Test (IBT) [35] allow to perform the direct tensile tests (i.e. mode I). These experimental techniques allowing the evaluation of interfacial bond strength and the tack coat efficiencies. Beside, the interface behavior in mode II and the shear strength can be evaluated from Ancona Shear Testing Research and Analysis (ASTRA) [36], Leutner [37] Layer-Parallel Direct Shear (LPDS) [3], DST Shear test [38], Direct Shear test with normal Load [15], Shear Fatigue Test [8] and Double Notched Shear Test (DNST) [28]. The EPCF – Essai de Poutre Console en Fatigue [39], Three Point Bending (3PB) tests on prismatic beams [40] and 4PB on prismatic beams (cyclic) [12] are other experimental techniques for the evaluation of mixed mode interface behavior. It should be noted that in these cases the interface behavior is described by an elasto-plastic model according to the Mohr–Coulomb criterion [14].

Since some years, optical techniques were increasingly applied to the interface behavior analysis. Among these experimental techniques Digital Image Correlation (DIC) [26–28] seem to be most adapted to analyze the interface influence on the local and the global behavior of asphalt concrete. Associated with full-fields techniques the DIC can be easily used to measure the displacement and strain fields at different scales.

The roughness is another parameter which provides a lot of interest in the characterization of interface behavior. Today, the volumetric patch technique (NF EN 13036-1) is the most common standard to calculate the surface Mean Texture Depth (MTD) in the road structure [41,42]. However, the alternative methods such as the profile comb, laser profilometer, 3D scanner and X-ray Computer Tomography (CT) allow the investigation the surface profiles [43,44]. The different kind of mixture by using steel balls with various size diameters are another technique which was tested in mode II [45].

3. Experimental materials and methods

3.1. Materials

The mechanical behavior of asphalt concrete was evaluated from the direct tensile test. The tests were carried out with three bi-layered asphalt concrete specimens obtained from two distinct layers of AC12 with a Carbon Fiber grid at the interface. The grid is a square mesh with 20 by 20 mm [40]. The tested material

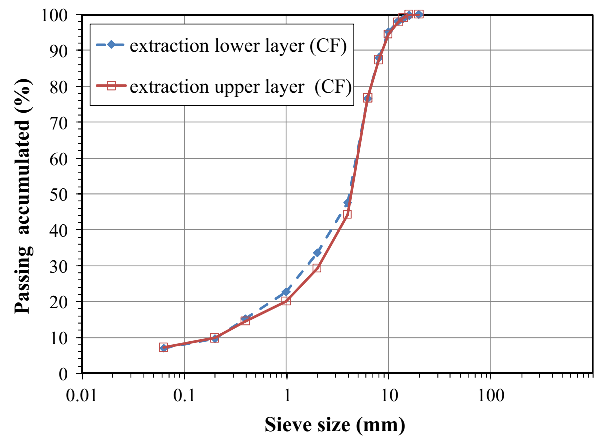

Fig. 1. Particle sizes curve for upper and lower layer for (AC-12).

was provided from the experimental section of the RILEM-SIB[1] project. The AC12 material is a typical Italian formulation, with 12.5 mm maximum aggregate dimension and 50/70 penetration bitumen dosed at above 5% by aggregate weight (Fig. 1).

The average void percentage porosity is around 11.55 (±0.74) and 12.71 (±0.72) for the upper and lower layers respectively. The tests were performed according with the hydrostatic standard NF EN 12697-6 [46]. According with EN-13808 [47], in both reinforced and unreinforced sub-sections an SBS polymer-modified tack coat emulsion classified as C 69 BP 3 was applied on the surface of the lower layer with a rate of 250 g/m^2 o residual binder (cf. [40]).

3.2. Direct Tensile Test (DTT)

The geometry and dimensions of sample named Direct Tensile Test (DTT) is shown in Fig. 2. As is shown the interface is located at the middle of both of layers. In order to apply the monotonic loading the bottom of specimen is fixed on the testing machine by rigid steel jaws. As regard the test boundary conditions, the bottom of specimen is fixed on the testing machine by rigid connections, when the top end is loaded in tension. The test is performed using a *Zwick electromechanical press* under displacement control (see Fig. 2). The cross bar rate of testing machine is 0.5 mm/min. All the tests were performed in the ambient conditions of the test room (20 ± 2 °C).

During testing the mechanical behavior of sample was measured by means of LVDT position sensor and a load cell of 50 kN with 0.5% of accuracy. In addition with the testing machine measurement devices, the sample deformation was recorded using the optical measurements by Digital Image Correlation and the Mark Tracking Method. These measurements allowed for determining displacement and strain fields. The optical device configuration consisted of an AVT Marlin F-201B with a Pentax 12.5–75 mm lens and a LED light source. Correla and Deftac software's, developed by PEM team of Pprime Institut of Poitiers [48], were used to calculate the mechanical fields. The estimating uncertainty of displacement is 0.026 pixels.

3.3. Measurement methods

As indicated above the displacement and strain mechanical fields were measured by means Mark Tracking method and Digital Image Correlation.

The Mark Tracking method was used to measure the global kinematic state by taking into account the loading device deformation. As illustrated in Fig. 2, in order to realize the measures several white marks were positioned on the steel jaws. The basic principle of Mark Tracking Method summarized in (Fig. 3) is based on comparison of two images acquired during the test, one before deformation and another one after deformation [49] The displacement of each mark is in fact the translation vector $\vec{u}$ in x and y directions of mark barycenter. In the present study the longitudinal strain ε_{yy} calculated by means the Mark Tracking Method represents the ratio between the average displacement of the marks $\overline{\Delta u_y}$ (where $\overline{\Delta u_y} = \sum_1^n |u_y^{i,\mathrm{upper}} - u_y^{i,\mathrm{lower}}| \big/ n$, where n is the mark number) and the initial distance between the lower and upper marks.

In order to analyze the interface influence in the local and global behavior of bi-layered asphalt concrete the Digital Image Correlation was proposed. This method allows also assessing the de-bonding occurring. By using DIC, the displacements were calculated by tracking the deformation of random gray speckle pattern applied to sample surface (Fig. 3). According to DIC principle prior to testing, a very

[1] RILEM-SIB: Réunion Internationale des Laboratoires et Experts des Matériaux – Testing and characterization of Sustainable Innovative Bituminous materials and systems, Task Group 4: Pavement Multilayer System Testing.