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Experimental investigation of tack coat fatigue performance: Towards an improved lifetime assessment of pavement structure interfaces

M. Diakhaté [a,*], A. Millien [a], C. Petit [a], A. Phelipot-Mardelé [b], B. Pouteau [c]

[a] Université de Limoges, GEMH-GCD, Bd J. Derche, 19300 Egletons, France
[b] Université Européenne de Bretagne, LGCGM, IUT de Rennes, 3 rue du Clos Courtel, BP 90422, 35704 Rennes Cedex, France
[c] Eurovia, Centre de Recherche de Mérignac, 22 rue T. Sabine, 33703 Mérignac, France

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ABSTRACT

This paper focuses on investigating the bonding fatigue performance between two asphalt concrete (AC) layers. For purposes of this experimental campaign, a customised double shear testing device was designed. Two interface conditions have been analysed herein: with and without a tack coat. Moreover, the corresponding fatigue behaviour has been analysed at two temperatures: 10 °C and 20 °C. As expected, the absence of a tack coat leads to a decrease in bonding fatigue performance. Since fatigue tests are highly time-consuming, a method that allows predicting the conventional interface fatigue law from accelerated shear fatigue tests has been proposed. Other novel findings on interface fatigue behaviour will also be discussed. In addition to these fatigue results, an interface failure model is proposed to evaluate the interface lifetime. Incorporating interface fatigue performance into pavement analysis proves to be a key parameter in describing *in situ* pavement conditions and assessing pavement durability.

1. Introduction

In the recent past, interface shear performance has been widely investigated [1–13], especially given that the behaviour of in-service pavements has on occasion revealed several types of premature distresses, potentially due to an inadequate selection of interface boundary conditions during the pavement design stage. During the design process, the currently held assumptions of full bonding vs. no friction between adjacent layers in fact fail to address practical realities. The stress distribution in a pavement structure is influenced by the bonding state at each interface [10,11]. Taking into account the interface bonding state in a pavement analysis therefore proves to be of great importance by improving the assessment of pavement lifetime (or residual lifetime).

In particular, if the necessary bonding level is not introduced at the uppermost interface, then the wearing course may become the only layer to withstand traffic loads (since shear continuity will be lacking at the interface); distresses thus appear earlier than expected. In addition, the shear stress level at the uppermost interface increases with rising traffic loads and thinner wearing courses. Field observations have underscored the need to ensure an excellent bond of adjacent layers, notably on road sections where vehicles are more likely to apply horizontal forces, such as small-radius curves, steep ramps and braking/acceleration zones [3,4].

Even though field observations on roads have highlighted the need to understand actual interface behaviour in order to more accurately compute the useful lifetime of pavement structures, the laboratory campaigns carried out were nonetheless restricted to monotonic tests (direct shear, pull-off, wedge-splitting, etc.). Raab et al. summarised the test methods and devices for the determination of bond between asphalt pavement layers regarding shear testing [12]. The practice of subjecting a pavement structure under traffic load to a fatigue loading is by no means a new technique, which makes it obvious that loads acting at the interfaces are also cyclic.

To simulate the repetitive load of moving vehicles, Romanoschi and Metcalf [3] proposed a laboratory test configuration to perform shear fatigue tests on asphalt concrete layer interfaces. The specimen is subjected to both a normal and shear load. To include the normal force, the testing device, developed by Romanoschi [4], allowed for the longitudinal axis of the test specimen being at a 25.5° angle with the vertical, so that the shear stress at the interface is half the normal stress. A vertical load is applied with a minimum of 10% of the maximum load and with a frequency of 5 Hz. Fatigue tests on two types of interface (with and without tack coat) were performed at 25 °C. Four normal stresses (0.50, 0.75, 1.00, and 1.25) were selected to be within the range of normal stress values encountered at the interfaces of road and airfield pavements.

* Corresponding author. Tel.: +33 5 55 93 45 28; fax: +33 5 55 93 45 31.
E-mail address: malick.diakhate@unilim.fr (M. Diakhaté).

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Elastic and permanent displacements at the interface in normal and tangential directions were recorded for each cycle, and the cyclic tests were stopped when the permanent shear displacement (PSD) at the interface reached 6 mm or when it was considered that the number of loading cycles corresponding to a PSD of 6 mm could be extrapolated [3,4,9]. The parameter ND1 (number of loading cycles that leads to an increase of PSD of 1 mm) gives information of the interface bond fatigue performance.

At the Technical University of Dresden (Germany), the development of a dynamic version of the Leutner shear test is under way. The asphalt concrete specimen is subjected to both a shear and normal force [13]. In this cyclic testing on the interface bond, different parameters such as temperature (−10 °C, +10 °C, +30 °C and +50 °C), normal stress (0–1.11 N/mm^2) and the loading function (sinusoidal function with amplitudes from 0.005 to 0.1 mm and a frequency from 1 to 15 Hz) were included. The purpose of the project was to find an ''interlayer bonding factor'' which can be used for pavement design in BISAR or in finite element programs.

This paper will present the results from a research project devoted to both the experimental and numerical study of fatigue shear behaviour at interfaces. One objective of this research has been to propose an additional failure criterion in the pavement design method. With most flexible pavement design methods, the structure is assessed on the basis of the tensile fatigue performance of bituminous layers as well as the rutting performance of unbound granular layers. These results will enable the pavement designer to evaluate the lifetimes of both interface bonding and the material layers. Incorporating interface fatigue performance into pavement analysis therefore serves as a key means of providing more accurate results (i.e. description of the *in situ* pavement conditions, pavement lifetime determination).

The interface fatigue performance between two distinct asphalt concrete (AC) layers will be investigated. Two types of interface conditions are analysed herein: with and without an asphalt tack coat. For purposes of this experimental campaign, a specific double shear testing device has also been designed and manufactured [14].

2. Experimental campaign

2.1. Presentation of the testing device

The GEMH-GCD laboratory (*Université de Limoges*, France) has successfully introduced a double shear test, based on the compact shear test, to investigate crack propagation within asphalt concrete under a mode II fatigue loading [15]. In the same laboratory, Diakhaté et al. used this double shear device (known as COLAREG) to conduct a feasibility study on the shear fatigue behaviour of tack coats [9].

The double shear test (DST) in the laboratory involves a specimen consisting of three layers bonded two-by-two with the same tack coat. The case of an interface without a tack coat can also be tested using this set-up. The two side layers (AC #1 and AC #3) are fixed during the test, and the central layer (AC #2) is subjected to a load (Fig. 1). To investigate tack coat shear behaviour, the advantage of a double shear test lies in the fact that both interfaces symmetrically undergo a relatively pure shear loading [14].

However, since the COLAREG device used in the previous study [9] does not allow conducting either oligocyclic or monotonic tests beyond fatigue, a more versatile device would need to be designed and built. During an initial stage, the finite element programmes Cast3M and NISA® were used to model the testing device. This study is intended to obtain a relatively pure shear loading at the interfaces by means of optimising both the specimen and device geometries. The second stage involves validating the manufacturing quality of the device (by shear loading at the interfaces) using optical methods [14]. Fig. 2 displays the completed double shear test device.

2.2. Asphalt concrete and interface conditions

Two types of interfaces are studied as part of this experimental campaign: the first, referred to as TC-70/100, calls for the asphalt concrete layers to be bonded with a tack coat; while the second entails bonding the two layers without a tack coat (WTC). The tack coat used in this campaign is a conventional, rapid-setting cationic emulsion (reference C65B4, according to the European Standard EN 13808:2004(F)); it contains approximately 65% bitumen (pen 70/100).

The two types of asphalt concrete selected for this experiment were manufactured in the laboratory. Both mixes have been formulated with the same pure bitumen (pen 35/50). The design characteristics of these common asphalt concretes are given in Table 1 below.

2.3. Production of DST specimens

The double shear test (DST) involves a specimen composed of three asphalt layers. Fig. 3 presents the method employed to obtain the desired specimen shape. The advantage of this method is that both interfaces exhibit the same characteristics, in terms of compaction, roughness, tack coat application rate, etc. Moreover, this method can be applied to field specimens (either slabs or cores).

To produce the desired specimen using the method in Fig. 3, the first stage consisted of creating a double-layered slab. After sawing the slab (stage #2), the two resulting parts were glued together (stage #3) with a two-component epoxy glue. Following polymerisation of the glue, a sawing process allowed extracting specimens with the specified geometry (i.e. $L \times H \times W$: 105 mm × 70 mm × 50 mm).

In the first stage of the previously presented method, a mould (measuring 600 mm long, 400 mm wide and 80 mm high) was used to prepare the double-layered slab. Once the hot mix asphalt (160 °C) had been poured into the mould, the French rolling wheel compactor (Fig. 4) compacted the mixture to a thickness of 50 mm, in accordance with European Standard NF EN 12697-33. After cooling for two hours, the temperature at the upper surface of the layer equalled approx. 40 °C and the tack coat was then uniformly applied at a rate of 300 g/m^2 (residual bitumen). This temperature (40 °C) was chosen because the tack coat was stored in a climatic chamber at 60 °C. Once the tack coat had been applied, a 2-h rest time was considered adequate to ensure the corresponding breaking process. Afterwards, the compaction process was repeated in order to produce the upper asphalt concrete layer (30-mm thickness).

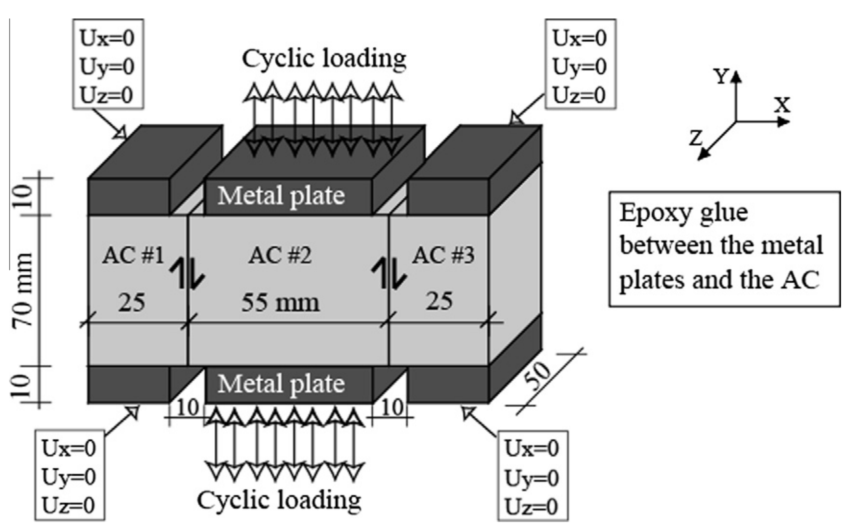

Fig. 1. Schematic diagram of the double shear test.