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Dynamic shear tests for the evaluation of the effect of the normal load on the interface fatigue resistance

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HIGHLIGHTS

- Investigation of the interface shear fatigue behavior between two asphalt layers.
- A regression law incorporating all the possible stress combinations is proposed.
- Isodamage curves quantify the influence of normal pressure on fatigue resistance.

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ABSTRACT

This paper focuses on investigating the fatigue performance of the interface between asphalt layers. The aim is to highlight the relationship between the state of stress and the interface fatigue failure. Several combinations of normal pressure and shear load amplitude have been tested to derive a comprehensive law. A new model is proposed to join the contributions of normal stress and shear stress to the interface fatigue behavior. The model is a regression surface in a 3D space where the stresses are the independent variables while the dependent one is the number of repetitions corresponding to characteristic moments of the test.

1. Introduction

Road pavement is a layered structure composed of different materials. Its life depends not only on the strength and stiffness of its individual layers but also on the bond between them. Several factors affect the interface behavior, and several issues affect the pavement when the interlayer bonding is poor.

The most common distress that can be caused from a low bonding level between layers is slippage cracking, especially at intersections and sharp curves. Premature fatigue, top down cracking, potholes, distortions and surface layer delamination can be other associated distresses. Due to the structural integrity decay of the pavement associated with these distresses, the analysis of the interface bond condition is very important.

2. Background

Shear testing is the most popular method to experimentally evaluate the strength behavior at the contact between pavement layers. Many devices have been developed to work in stress control or in strain control modality and to apply various combinations of shear and normal load.

Pure direct shear tests are most widely used due to their simple arrangement. The Leutner test [1] included in the SN 671961 since 2000, and its evolution, the Layer-Parallel Direct Shear Test (LPDS) [2] are direct shear tests. The same configuration is also used in the FDOT device [3] and in the testing machine used by Mrawira and Damude [4]. All of them are without normal loading and with several shear deformation rates.

Alternatively, direct shear tests with normal loading have been used to highlight the strong relationship between the normal load and the interface shear strength. The response curve for this test is characterized by a peak and a residual friction trend [5], which is also used for interface response modeling. The first device capitalizing on this latter approach was developed by Uzan et al. [6]. Other devices of the same type include the ASTRA apparatus from

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Polytechnic University of Marche [5], the Superpave Shear testing Machine (SST) [7], the Louisiana Interlayer Shear Strength Tester (LISST) [8] and the two devices designed and developed at University of Rome Sapienza [9,10].

All of these devices assess the interface strength by measuring the increase of the shear stress with the shear displacement raising. To simulate the vertical pressure transmitted by vehicular loading at the interface level, the shear test is performed at various compression levels. The test results show that as normal pressure increases, shear strength increases. Frictional yield models can be used to represent this type of interface response.

To relate the actual stress in the pavement to the strength model, Ozer et al. [11] introduced the concept of the stress ratio. This parameter is defined as the ratio between the predicted interface stresses and the proper interface shear strength. If there is a quantitative relationship between the stress ratio and the failure rate, the stress ratio could be one of the ways to estimate critical interface conditions for different pavement structures and materials.

Surely, similar to other pavement failure mechanisms, debonding and slippage cracking do not occur after a single, large stress; rather, they occur after repetitive stresses. Traffic related stresses are low with respect to the peak resistance, but they are applied a very large number of times over the pavement's service life. Dynamic tests seem to better simulate the stress conditions experienced by pavement materials for characterizing interface shear behavior. Such tests are simple from a theoretic point of view but are complex in practice. Given the difficulty of performing dynamic tests and the simplicity and short turnaround of the monotonic shear test, few papers can be found regarding dynamic evaluations of interface shear strength. Therefore, the monotonic shear test is preferred when the goal of testing is the comparison of different tack treatments.

Romanoschi and Metcalf [12] performed tests in which the specimen was held at an angle of 25.5° between the longitudinal axis of the specimen and vertical such that the ratio between the shear load and the normal load was 0.5. To simulate a vehicle passing at 50 km/h, in the dynamic mode the vertical load applied by the loading machine was set to 10% of the maximum load recorded in monotonic tests at a frequency of 5 Hz for a total period of 0.2 s and a pulse length of 0.05 s. The parameter selected for comparing fatigue behavior was ND1 or the number of load cycles corresponding to an increase of the permanent shear displacement (PSD) of 1 mm. A high ND1 value corresponds with a durable interface.

The Double Shear Test (DST) [13,14] must also be considered. This testing machine works in shear mode on parallelepiped specimens composed of two symmetrical shear bands identified by four pre-cuts. Displacement and force control are applied with sinusoidal loading at 10 Hz without a rest period. Two fatigue criteria were analyzed by the authors. The first is related to the 50% reduction in the modulus, which assumes that failure happens when the initial stiffness has decreased by 50%. The second criterion is based on the damage growth trend, wherein the inflection point read on the damage vs. number of fatigue cycles curve is assumed to be the failure point. Furthermore, in the "3MsCE" laboratory at the University of Limoges (France), a novel device called the Modified Compact Shearing (MCS) has been developed [15] as an evolution of the Double Shear Test. The N_f, or number of fatigue cycles, has been counted as the number of repetitions that correspond to half of the initial force, shear stiffness, or displacement, depending on the working mode. The "resistor failure criterion" has also been considered to evaluate fatigue interface behavior. This method uses the failure of resistors to detect the interface failure. The relationship between the simple monotonic test and the shear fatigue performance has been investigated to examine the influence of the loading rate on the interface shear strength.

A non-conventional procedure to evaluate the stiffness and shear strength of geosynthetic interlayers has been developed by Vismara et al. [16]. A double layer beam, mechanically notched in the middle of the lower section, controlling the initial point of the fracture, has been subjected to a compressive haversinusoidal load of 5 Hz, until total failure. Four peak loads were chosen among 60% to 30% of the tensile strength measured with the Indirect Tensile Test.

Different reinforced bituminous interfaces have been investigated by fatigue analysis by Ferrotti et al. [17] using a 4-point bending test device working in a stress-controlled mode with a sinusoidal load ranging between 0 and 3 kN at 1 Hz. The failure criterion has been defined as the number of loading cycles corresponding to the flex point of the permanent deformation curve.

A tack coat shear fatigue model has also been evaluated by Xiaoyang et al. [18] based on direct shear fatigue tests. The strength envelope and the shear stress critical boundary analyzed by finite element method have been compared.

3. Objective

The objective of this paper is to contribute to asphalt layer interface characterization. In this field the effect of the normal load on the shear strength behavior has been widely investigated with different findings [6,12] related to specific interface treatments. Conversely, only few studies have been developed on investigating dynamic interface shear behavior.

The need to complete the interface shear investigation with dynamic experimentations, and the design of a machine that can be simple to install and easy to use, have led to the development of the SDSTM (Sapienza Dynamic Shear Testing Machine). A guillotine type working scheme has been adopted, modified with the addition of a piston that presses the specimen on either end. The fatigue shear response will be analyzed considering the results of specimens with the same interface treatment.

4. Testing equipment

The Sapienza Direct Shear Testing Machine (SDSTM) is able to test double layer cylindrical specimens with a diameter of 100 mm. In the working scheme, the specimen is held in two moulds with a gap between the two restraints of 1 cm. The interface must be placed in the middle, leaving 0.5 cm from the edge of each mould, as it is commonly accepted [19].

A dynamic loading machine applies the shear load (T) on one half of the specimen while the other half is fixed, preventing movement. The sliding of the moving mould is allowed by low friction guides. The normal load (N) is added by a pneumatic actuator, which applies force to the specimen by two opposing plates. A ball bearing plate is also located on the face of the moving specimen to allow failure growth. The device is equipped with LVDT for the interface displacement measurement. The device's most important innovation is the ability to evaluate the interface shear fatigue behavior under dynamic conditions. The maximum vertical capacity of the loading machine is 100 kN with load frequencies up to 5 Hz. The control system allows the application of any load profile. The working scheme and device details are shown in Fig. 1.

5. Experimental program

The experimental program developed for this study concerns only one type of interface. The fatigue performance has been investigated under different stress conditions, with and without normal pressure.