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Improved understanding of grouted mixture fatigue behavior under indirect tensile test configuration

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HIGHLIGHTS

- Fatigue and modulus tests were performed on grouted and traditional asphalt.
- Classical fatigue modeling did not satisfactorily apply to grouted mixture.
- The filling process enhanced asphalt structure heterogeneity.
- Grain arrangement and filling level were taken into account by measuring stiffness.
- Stiffness was explicitly introduced as a parameter in the fatigue model.

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ABSTRACT

This paper focuses on the long-term performance of a grouted mixture, a relatively new pavement material which consists of an open grade asphalt concrete whose voids are filled with cement mortar. Its peculiar characteristics, depending on mix design and level of filling, induce a variability of its mechanical behavior. The purpose of this paper is understanding how such variability affects the fatigue properties of the material, under indirect tensile test configuration. Experimental results have revealed a remarkable influence of stiffness properties on fatigue life. Following this observation, the fatigue behavior of grouted mixture is described through a new analytical model, which explicitly introduces the dependence of the fatigue life on the stiffness modulus. Comparative analysis demonstrates that the proposed analytical model significantly outperforms traditional fatigue modeling for the peculiar type of investigated composite pavement system.

1. Introduction

1.1. Background

Road construction and renovation in Europe are mainly undertaken by employing either flexible (FP_s) or rigid pavements (RP_s). FP_s represent a consolidated and widespread technology, easy to construct, open and patch, and exhibiting good serviceability and riding quality (with jointless surfaces). On the other hand, RP_s possess a comparatively larger bearing capacity and durability [1] but more construction issues. Semi flexible pavements (SFP_s) are an emerging alternative solution that can overcome the shortcomings of both technologies, while effectively combining their best features [2].

Such hybrid solution consists of an open grade asphalt concrete with 25%–35% voids, filled with a cement mortar. This is known in the literature as Grouted Macadam [3] or Combi-Layer [4] technology. The use of a grouted asphalt concrete is suitable in applications requiring bearing capacity and rutting resistance, e.g. in industrial areas, airport runways, container terminals, bus stops and harbors, typically characterized by slow and heavy traffic [5]. In similar conditions, a fuel and chemical-resistant surface that is highly resistant to fuel and oil spillage represents an additional remarkable quality. SFP_s are also a great design solution for long tunnels, which must respect specific safety standards [6]. To this aim, Toraldo [7] stated that grouted mixtures are suitable for tunnel pavement applications, as they can outperform both RP_s and FP_s in terms of fire resistance.

Grouted pavements are made through two successive phases. First, the open-graded asphalt is laid down using the normal equipment for the construction of FP_s. Secondly, after asphalt' cooling, the grout is spread over the surface, with the help of rubber

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scrapers, penetrating the voids of the asphalt throughout the thickness. The enhanced properties of this composite percolated material highly depend on void connectivity. The grout must possess an adequate workability so as to flow through the voids and completely fill them. Unfilled voids may cause premature pavement failure [8]. Assuming that voids are filled with grout, Ding stated that higher void content results in a stiffer and stronger material [9].

Fang et al. [10] studied cement slurry formulation, including different kinds of penetrants, and concluded that chemical additives are essential for a high performance product. Anagnostopoulos [11] investigated the effects of different types of superplasticizers on the mechanical properties of cement mortars characterized by different water-cement ratios. Agostinacchio et al. evaluated how the performance of the grouted mixtures is affected by curing conditions and temperature [12]. According to Anderton [13], aggregates for grouted mixtures should be sound, tough, durable particles crushed and sized with a relatively uniform gradation. Husain et al. [14] investigated the noticeable difference in volumetric properties and durability of SFP_s produced using three different aggregate gradations. Regarding the binder content of open-graded asphalt, literature evidences an optimal value range between 3.5 and 4.6 by mass of mixture [8,15,16].

Currently, literature shows few studies about the engineering properties of grouted mixture and its mechanical behavior needs further investigation to be fully understood. In particular, experimental and theoretical studies devoted to investigating the fatigue behavior of such materials, whose understanding is essential for pavement design in real applications, have not yet been sufficiently addressed.

1.2. Objective and experimental program

The grouted mixtures represent an interesting design solution in many applications in the civil engineering field. The material performance is strictly related to the in-situ homogeneous characteristics depending on the effectiveness of the construction procedure. However, the in-situ reproduction of laboratory conditions cannot be always guaranteed and, in practice, a certain material heterogeneity has to be expected.

In the aforementioned context, the main objective of this research was to investigate the fatigue properties of a grouted mixture, studying its long-term performance in relation to samples' features. The authors decided to use a standard slurry formulation (water and cement mix), without any chemical additives, to investigate a design solution widely adopted by Italian technicians. The study concerned also a conventional Italian dense-grade asphalt concrete for providing comparative values for the grouted mixture, which, after void filling, is in fact a closed mixture.

In order to fully characterize both standard and filled mixtures, each specimen was also subjected to modulus tests. In fact, as fatigue properties determination is usually required to identify the long-term performance of a mixture, whereas the stiffness modulus represents a primary input parameter within most of the mechanistic-empirical pavement design methods, it would be a good practice to perform both stiffness and fatigue measurements in order to carry out a complete mechanical characterization of an asphalt concrete. The obtained results allowed the identification of possible correlations between stiffness and fatigue properties. The experimental results of the research showed that the classical fatigue modeling based on Wöhler curves [17] provides a poor representation of the behavior of the tested specimens made of open grade asphalt concrete filled with cement mortar. As discussed in the paper, this could be attributed to the significant spatial variability of the quality of mortar filling. Thus, a new analytical model is proposed where the elastic modulus of the pavement is explicitly introduced as a parameter in the fatigue law.

The testing program consisted of dynamic indirect tensile fatigue tests (ITFT), according to EN 12697-24 [18] and dynamic indirect tensile stiffness modulus (ITSM) tests, according to EN 12697-26 [19]. Indirect tensile fatigue tests, utilizing cylindrical specimens directly cored from an existing pavement, allow evaluation of in-situ behavior of materials. Even though ITFT suffer from concerns over the accumulation of permanent deformation in the vertical direction, Read and Collop [20] found that under the recommended test conditions (120 ms loading time and test temperature less than 30 °C) tensile failure is the dominant mode in asphalt mixture specimens. In the presented experiments, both fatigue and stiffness modulus tests were carried out at a controlled temperature of 20 °C. Specimens were conditioned to the test temperature for 4 h before running the test.

The experimental program overall included 45 specimens, 30 for the grouted mixture and 15 for the traditional mixture. For the grouted mixture and for the traditional mixture 6 and 3 slabs were manufactured, respectively. From each slab, 5 samples were cored. Being ITSM a non-destructive test, all specimens were subjected first to the stiffness and then to the fatigue test. ITFTs were carried out at different stress levels, from 250 to 600 kPa. All tests were performed at the Road Infrastructures Laboratory of University of Perugia.

The paper is organized as follows. The experimental methodology is presented in Section 2. Section 3 presents the results and the related discussion, ending with the development of the new analytical fatigue model. Finally, Section 4 ends the paper with proper conclusions.

2. Experimental methodology

2.1. Asphalt mixture design

Two different types of materials were studied: an open grade asphalt concrete filled with cement mortar (FAC) and a traditional hot mix asphalt (HMA) with an air void content of 5%. For the grouted mixture, a void percentage of 25% was selected in order

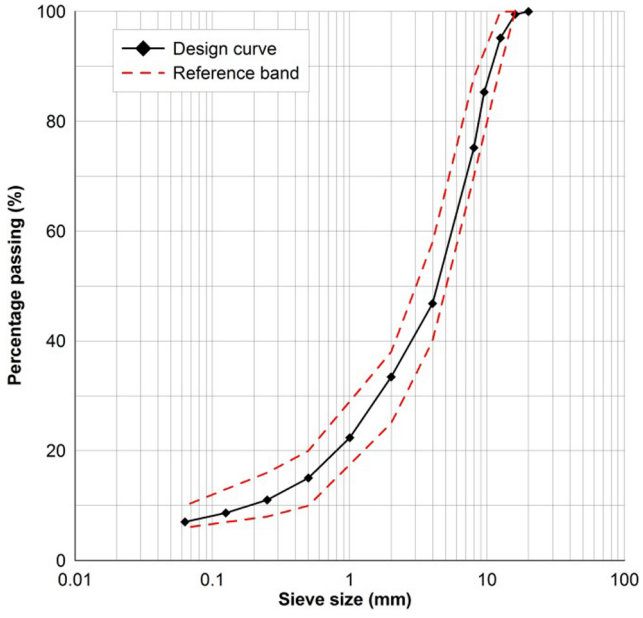

Fig. 1. Gradation curve for hot mix asphalt.