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Field performance and fatigue characteristics of recycled pavement materials treated with foamed asphalt

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HIGHLIGHTS

- Pavement material properties were estimated from field measurements.
- Laboratory fatigue characteristics of the layer mixes were used in the analysis.
- The contribution of the AC overlay in the CIR pavement condition was investigated.
- The curing of the foamed material is important for the damage of the AC overlay.

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ABSTRACT

The paper concentrates on the field performance and the fatigue characteristics of cold recycled materials treated using foamed asphalt (FA). For this purpose, field measurements were performed approximately one month and one year after the pavement was placed in service. Based on this data and laboratory analysis results, there is an indication that fatigue is a minor distress factor for both the cured FA material and the asphalt concrete (AC) overlay which covers the FA. The contribution of the AC overlay in the structural condition of the cold recycled pavement is vital during the early days of the pavement life.

1. Introduction

As the cost of hot mixed asphalt mixtures continuously increases and the availability of good materials is limited, Cold In-Place Recycling (CIR) offers an environmental friendly and attractive alternative to other pavement rehabilitation options. CIR is an advantageous rehabilitation technique that is eminently suited for the reworking of the upper layers of distressed pavements. Among several cold recycling systems, the foamed asphalt technique [1] has gained popularity over the last two decades for its efficient use of salvaged construction material. The use of the foamed asphalt technique in rehabilitating road pavements was given a boost in the 1990s through the incorporation of advanced cold recycling machine technology. Worldwide since 1991 many foaming systems were developed after the ending of the Mobil patent rights on the nozzle [2].

Information concerning foaming procedures in the laboratory, as well as related construction aspects, although not standardized, is satisfactorily documented in international literature, as for example in [3] and [4]. However, limited information is provided concerning the field performance and the fatigue characteristics of recycled pavement materials treated with foamed asphalt (FA) and when published it is usually focused on low and medium volume roads.

Foamed asphalt treated materials have strong cohesive bonds and a relative high resilient modulus (in comparison to untreated materials) as long as the cohesive bonds is retained. This intact condition is maintained for a certain period of traffic loading and is referred to in [5] as the "effective fatigue life phase". Eventually, the cohesive bonds are destroyed through the repeated flexing of the material under traffic loading to the point where the effective resilient modulus of the material has decreased to a value comparable to that of an untreated granular material and the layer is referred to as being in an "equivalent granular state".

Following the research done by [6] on the behavior of foamed asphalt treated materials and based on Heavy Vehicle Simulator (HVS) tests [7], the resilient modulus of the treated material

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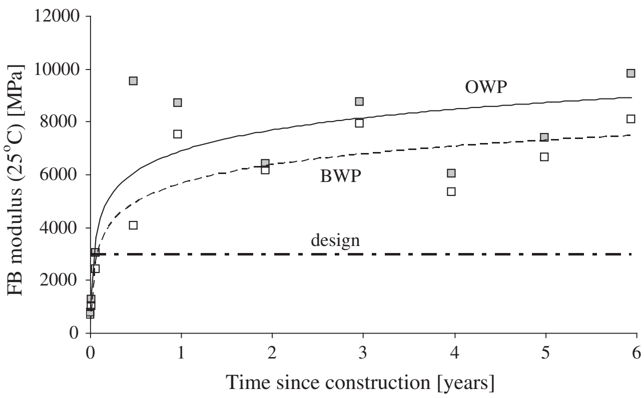

Fig. 1. Backcalculated FA moduli (25 °C) [9].

initially starts at a relatively high value and then decreases under the action of traffic until a constant resilient modulus or stiffness state is reached. The latest ("constant stiffness state") is a scientific interpretation replacing the term "equivalent granular state" [6]. The load repetition from the initial state to the constant stiffness state is more recently referred to in international literature as the "stiffness reduction phase" replacing the term "effective fatigue life phase" [6]. However, an area of concern was the lack of field performance data, as well as differences between the performance under accelerated testing versus long term field conditions [8]. More recent analysis results of Non Destructive Tests (NDT), on a CIR pavement treated with foamed asphalt [9] show no reduction of the modulus of the FA recycled material with time and traffic (see Fig. 1).

In order to gain more information about the field performance of foamed asphalt treated mixes, a field experiment was undertaken by the NTUA Laboratory of Pavement Engineering on sections of a heavily trafficked Greek highway pavement (approximately 1.2×10^6 ESALs per year). In situ Non Destructive Tests (NDT) for approximately one year after the pavement was placed in service laboratory tests and a data analysis research study was performed. The deterioration of the materials during the design period was estimated by calculating the in situ critical strains during the early life of the pavement and using appropriate fatigue laws. The main findings of the data analysis concerning the conducted field experiment are presented and discussed in the present research work.

2. Experimental test sites and foamed asphalt mix design

The experiment was carried out on two test sections with different FA mix compositions and "soil-support" of the FA treated layer hereafter referred to as S1 and S2, respectively. The term "soil support" for the FA treated layer is defined as the remaining layer beneath the recycled layer, which "supports" the FA layer. The test section S1 provides a stiffer "soil support" for the FA layer, than test section S2. Prior to the CIR implementation, foamed asphalt mix designs were undertaken on several different blends of material recovered from test pits. The blends had differences in the grading, due to the fact that several reclaimed asphalt pavement (RAP) percentages were used. However, since from the nature of the CIR technique the material is inconsistent, the important aspect is the achieved in situ mix characteristics and respectively its behavior. These blends were treated with foamed bitumen using the appropriate laboratory unit and several briquettes were manufactured for testing purposes to determine the indirect tensile strength (ITS), the unconfined compressive strength (UCS), the cohesion (c) and the angle of internal friction (Φ), as well as the determination of the indirect tensile stiffness modulus (ITSM). The aim of the mix design was to establish the application rates for foamed asphalt and active filler (cement), to achieve optimal strengths and to determine the strength characteristics of the mix.

According to the mix design, 3% foamed asphalt (from 80/100 Pen grade bitumen) and 1% ordinary Portland cement as active filler was used for the composition of the FA mix in the case of test section S1. The decision to introduce 1% cement was based on the improvement in the achieved soaked strengths. The related FA mix is referred to hereafter as "mix I". Mix design tests were undertaken using 100 mm diameter Marshall-specimens compacted with 75 blows to each face and cured for 72 h in an oven at 40 °C according to [4]. The cured samples were soaked for 24 h before testing in "wet" conditions. Similarly, a standard mix design of 2.5% foamed asphalt and 1% cement was adopted for the test section S2. The related FA mix is referred to hereafter as "mix II". The difference in foamed asphalt percentage is attributed to the differences in the composition of the in situ pavement materials. Optimum blend components were based on the ITS results for the 100 mm briquettes and the UCS results for the 150 mm diameter (120 mm high) briquettes, according to [4]. The ITS values were 280–498 kPa (dry) and 225–469 kPa (wet), while the UCS values were 1900–2400 kPa (at equilibrium moisture content). The dry density values ranged between 2007 and 2183 kg/m^3. Following the laboratory mix design data and according to preliminary laboratory tests results at 25 °C, the maximum FA stiffness modulus was considered to be 3000 MPa for mix I (test section S1). In the case of test section S2, due to the different FA mix composition, a lower modulus value for mix II was determined from laboratory tests. For this reason, a more conservative value (1500 MPa) of the FA modulus was considered for mix II.

3. Field data collection

Data from measurements (NDT) performed approximately one and twelve months after the pavement was placed in service were used for further analysis. The data collected approximately one month after the pavement was placed in service was utilized for the evaluation of the performance during the first days of the life of the pavement. Following research concerning relevant CIR pavements and FA recycled mixes (see Fig. 1) the curing of the FA material is expected to be completed one year after construction. For this reason, measurements were also performed approximately twelve months after the pavement was placed in service. This data was utilized for the evaluation of the performance of the CIR pavement after completion of the curing of the FA material.

In situ testing was performed using the Falling Weight Deflectometer (FWD) on the heavy traffic (right) lane at nine specific test points of the test section S1 and at eight test points of the test section S2. For the purpose of the research, i.e. for estimation through back calculation of the in situ moduli of the recycled pavement materials, the above mentioned number of test points was assumed to be sufficient. Measurements were conducted on both the outer wheel path (OWP), where the pavement was distressed from traffic loading (trafficked path), as well as the respective in between wheel path (IWP), where the pavement was essentially unloaded (see Fig. 2). The thickness of the CIR pavement layers was estimated by analyzing the in situ collected geophysical data using Ground Penetrating Radar (GPR) [10] and the proper software [11] for post-processing. During measurements 12 months after the pavement was placed in service, a limited number of cores were drilled from the AC overlay, as well as the FA layer. It was not feasible to extract cores to the full depth of the FA layer one month after the pavement was placed in service, e.g. before the completion of the curing of the material. The core thicknesses were used as input data during the GPR analysis procedure.

Due to the fact that the focus of the research was to investigate the in situ recycled pavement behavior, no detailed comparison between the laboratory design and the materials in the field was performed and no other tests were conducted.

4. Backanalysis

A thorough field data analysis was performed including a detailed backanalysis using appropriate software Elmod [12]. Considering the level of the subgrade at the bottom of the remaining layer, the backanalysis model consisted of four layers. For backanalysis purposes, the thicknesses of all layers were estimated using the GPR analysis results. Fig. 3 shows the pavement modeling for the backanalysis, including the loading condition parameters (R, P) and the layers characterization through the