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Evaluation of fatigue cracking performance of asphalt mixtures under heavy static and dynamic aircraft loads

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HIGHLIGHTS

- Asphalt mixes used as surface in airfield taxiways and aprons were analyzed.
- The mixes were compared based on their fatigue cracking performance.
- The BRIC and HMA PG82-22 mixes performed better than the FAA P-401.
- The WMA–RAP and HMA PG70-22 mixes performed similarly to the FAA P-401.

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ABSTRACT

This laboratory and analytical study investigated the pavement's mechanical responses in terms of strains at the top and bottom of the asphalt surface layer for a number of modified asphalt mixtures. The purpose was to identify their potential for use in airfield aprons and taxiways that are subjected to heavy, slow-moving aircraft loads. The effects of these loads on fatigue behavior were evaluated in ABAQUS™ using the material properties determined in the laboratory. The findings indicated that a number of mixtures, including modified mixtures and warm mix asphalt, experience strain levels comparable to the FAA standard P-401 asphalt mixture.

1. Introduction

Fatigue cracking is one of the major concerns in airfield flexible pavements especially when these pavements are subjected to heavy aircraft loads. The cracks initiate at the bottom of the asphalt surface where tensile stresses and strains are the highest and mitigate to the surface [22]. Fatigue cracking can also initiate at the surface of flexible airfield pavements, due to excessive tensile strains near the outer edge of the aircraft wheel [1]. Some of the factors associated with this fatigue cracking include structural support, asphalt content, air voids and aggregate characteristics, temperature, stiffness, thickness, and traffic [22,30]. The relationship between load-induced failure and strain in flexible pavements is dependent on the horizontal tensile strain at the bottom of the asphalt layer and the elastic modulus of the asphalt mixture [10]. The asphalt layer in flexible airfield pavements are currently designed with stiff, dense-graded hot mix asphalt (HMA) mixtures according to the Federal Aviation Administration (FAA) P-401 specifications [12]. These specifications, developed to provide guidance on the production of asphalt concrete for airfield applications, require the production and placement of dense-graded HMA mixtures with a 25-mm maximum aggregate size and state-specific Superpave penetration grade (PG) binders.

In recent years, asphalt mixtures used in highway pavements have been modified to improve aging, rutting, and fatigue cracking performance. Among these asphalt mixtures, the most commonly used materials include a variety of polymer-modified mixtures, warm mix asphalt (WMA), and reclaimed asphalt pavement (RAP).

Polymer-modified binders have been used in airfield flexible pavements to accommodate the effects of high ambient temperature and heavier aircrafts by increasing the stiffness of the asphalt mixture. Consequently, the increase in stiffness reduced the rutting potential of the asphalt mixture. The potential of polymer-modified asphalts to improve asphalt pavement rutting resistance for highway and airfield pavements is well documented [28,25,15,21].

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However, the fatigue life of asphalt mixtures might either increase or decrease with the use of modified binders [31,17]. Studies have shown that modified asphalt mixtures may reduce the number of strain cycles to failure. However, it was found that the same modifier used with different asphalt increased the fatigue life [19]. The selection of a polymer-modifier may have significant effects on the ultimate asphalt field performance [28].

The highway industry has implemented RAP in the aggregate portion of the asphalt mixture as a mean for achieving stiffer mixtures. Flexible pavements containing RAP have been evaluated by the U.S. Army Corps of Engineers (U.S. ACE) in airfield applications [18], and the addition of RAP has been reported to increase the dynamic modulus of airfield asphalt mixtures [17]. However, with the increase in stiffness, the concern of the mixture resistance to long-term fatigue cracking arises. Generally, the use of RAP increases the mixture laboratory resistance to fatigue cracking [29].

WMA is a relatively new technology that allows the reduction of the production and compaction temperatures of asphalt mixture by as much as 75 °C. This is achieved by altering the HMA with water-, organic-, or chemical-based additives. The purpose with WMA is to produce asphalt mixtures with comparable strength, durability, and performance characteristics as a conventional HMA, but at significantly lower production and compaction temperatures [8]. This technology was first introduced in airfield pavements in 2006 at the Boston Logan International Airport (runway 4R/22L) [8]. WMA was also paved at the Stevens Anchorage International Cargo Airport (on the taxiways) and at the Chicago O'Hare International Airport (on the runways and taxiways). Lower production temperatures can potentially improve pavement performance by reducing binder aging, providing added time for mixture compaction, and allowing improved compaction during cold weather paving [8].

Another emerging asphalt technology is the performance-based mixture known as bottom rich intermediate course (BRIC). This mixture is usually placed in flexible highway perpetual pavements between a concrete structural layer and an HMA overlay to minimize the development of cracking due to joint movement in composite pavements [27]. The implementation of BRIC allows for a thinner flexible pavement section compared to pavements using conventional HMA. This type of mixture reduces the potential for fatigue cracking and structural rutting and limits any pavement distress to the surface lift [26]. Due to the different loading configuration and frequency applied in an airfield pavement, the BRIC was analyzed as a surface lift in this study. This mixture was considered for this study because the load repetitions over the design fatigue life in airfield pavements are much lower, up to twenty times less, than those experienced in highways [9].

1.1. Objectives

This study investigated how the mechanical responses of a broad range of asphalt mixtures compare under heavy static and dynamic airfield loads using laboratory-measured fatigue cracking properties of the mixtures. The main objectives of this study are as follows:

- to measure the cycles to failure of a broad range of asphalt mixtures according to the Texas Department of Transportation (TxDOT) overlay tester specifications;
- to determine mechanical responses in terms of tensile strains and stresses at the bottom and top of the asphalt surface layer under these static and dynamic aircraft loading through a finite element analysis (FEA);
- to determine the relative pavement fatigue life of the mixtures using the FAA Rigid and Flexible Iterative Elastic Layered Design tool, FAARFIELD (FAA, 2009).

Accomplishing the objectives will allow for the comparison of the mechanical responses and predicted fatigue life of various asphalt airfield pavement subjected to heavy, standing and slow moving aircrafts typical of airfield taxiways and aprons. The findings from this study will assist in discerning whether or not other types of asphalt mixtures can provide fatigue resistance properties comparable to those of the FAA P-401 mixture, making them viable options for use in airfield aprons and taxiways. As the highway pavement industry continues to move forward with the implementation of more innovative asphalt mixtures, it is essential that research be conducted in order to determine whether and how best the airfield sector can benefit from the characteristics of these same mixtures.

1.2. Scope

This study is an expansion of a previous study [16] that focused on evaluating mechanical responses (stresses and deflections) of a broad range of mixtures used as surface course in airfield pavements especially in taxiways and aprons where aircrafts are standing or slow moving (4.8 km/h.). This study focuses on evaluating mechanical responses in terms of strains at the bottom of the same asphalt mixtures presented in the previous study [16]. Mixtures analyzed in this study include those modified by addition of polymers, lower production and compaction temperatures, addition of reclaimed asphalt pavement to the aggregate portion, or by implementing alternative aggregate gradation. Laboratory testing of laboratory-compacted specimens was conducted to determine the cycles to failure according to the TxDOT specifications. Tensile strains at the top and bottom of the surface course were obtained using the three-dimensional (3-D) FEA software, ABAQUS™ [32]. The FAARFIELD software was used to compare the design fatigue life of the different mixes for an airfield pavement.

2. Methods and materials

2.1. Materials

A total of five modified asphalt mixtures were tested and analyzed in this study. The baseline case was a dense-graded asphalt mixture that met all the FAA P-401 mixture specifications [12]. The other four modified asphalt mixtures were obtained from recent highway field projects and consisted of WMA with 35% RAP added; two HMA mixtures with two different modified binder grades (PG82-22 and PG70-22); and, a BRIC mixture. All of the mixtures, except for the BRIC, have similar aggregate gradations and asphalt contents.

The BRIC mixture is typically used in flexible highway perpetual pavements as an intermediate layer placed between a concrete structural layer and an HMA overlay [27]. The BRIC mixture features finer aggregates than to the other mixes. As a result, the BRIC mixture has the highest binder content, but a portion of this binder content is absorbed by the mineral aggregates. The asphalt absorbed may improve the asphalt mixture's strength due to the increased mechanical interlocking [23]. Table 1 summarizes the features of the mixtures and their volumetric properties, while Fig. 1 presents the corresponding aggregate gradations.

2.2. Laboratory testing

There have been numerous efforts on the development of asphalt performance tests to relate laboratory-measured parameters to predicted distresses in highway pavements. The most recent test that can be conducted in the Asphalt Mixture Performance Tester (AMPT) is the Overlay Test [34], which originated with the purpose of simulating the opening and closing of joints or cracks in an asphalt pavement (Fig. 2).

This test is performed in accordance with the TxDOT test procedure Tex-248-F [33]. The overlay test assesses the mixture's resistance to crack propagation and correlates well with the field cracking performance for both composite pavements and flexible pavements [35,7]. The overlay test is performed at 25 °C with a minimum opening width of 0.625 mm. The test measures how many loading cycles it takes for a specimen to fail. Each cycle consists of five seconds of loading and five seconds of unloading. In this test failure is defined as 93% reduction of initial load or 1200 cycles, whichever comes first. The specimens can be prepared from either field cores or from Superpave Gyratory Compactor (SGC) molded specimens.