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# Evaluation of fatigue crack behavior in asphalt concrete pavements with different polymer modifiers

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ABSTRACT

Fatigue crack has been recognized as one of the main forms for structural damage in asphalt concrete pavements. Under the action of repeated vehicular loading, deterioration of the asphalt concrete (AC) materials in pavements, caused by the accumulation and growth of micro and macro cracks, gradually takes place. Existing prediction models in asphalt concrete pavement typically do not take the interaction and dependencies between micro and macro mechanics into account. In this research, the fatigue damage models and failure criteria are established based on the Indirect Tensile Fatigue Tests (ITFT) and Indirect Tensile Stiffness Modulus (ITSM) tests carried out on AC materials with different kinds of polymer modifiers. These additives are Polypropylene (PP), Crumb rubber (CR), Cellulose fiber (CF), Asbestos fiber (AF) and Gilsonite (GS). Fatigue damage model, based on continuum damage mechanics, describes the formation of micro-cracks and crack propagation developed in the wearing course materials (ACWC and SMA). With the fatigue damage models, finite element analysis is carried out to study the crack resisting performance of the wearing course materials in a flexible pavement structure.



## 1. Introduction

In order to provide comfortable ride and withstand the effects arising from traffic loading and climate, pavement materials should be designed to achieve a certain level of performance and the performance should be maintained during the service life [1,2]. Asphalt concrete (AC) is the most commonly used material in pavement because of its superior service performance in providing driving comfort, stability, durability and water resistance [3,4]. As asphalt concrete wearing course (ACWC) is the first layer in the pavement structure, the material should be able to sustain stresses caused by direct traffic loading without causing premature cracking [5].

The fatigue resistance of AC mixtures is its ability to withstand repeated bending without fracture. Fatigue manifests itself in the form of cracking from repeated traffic loading. Little cracking on highway and airport runway can mean the start of something serious. Most analyses utilize flexure stresses or strains on the underside of the AC pavement layers to assess the pavement lives [6] and fatigue behavior of the AC mixtures is characterized by the slope and the relative level of the stress or strain vs. the number of load repetition to failure [7,8]. These methods do not model crack propagation but require extensive tests and use of fracture mechanics to develop mechanistic relationships to describe crack development in asphalt concrete. This approach is inherently complex and the fracture mechanistic concept in fact does not describe the gradual deterioration of asphalt concrete material strength under cyclic loading [9]. In fact, damage can be defined as continuum change in material subject to unfavorable mechanical and environmental conditions that result in a decrease in strength [10,11]. The micro-damage of the material leads to the crack initiation and the accumulation of micro-damage results in the propagation of crack [12,13]. Such characterization can give a more realistic description of the AC material response under traffic loading. This research studies the characterization of micro-damage of asphalt concrete materials during the fatigue cracking process.

The main objective of this research is to characterize the fatigue cracking behavior in terms of micro-damage mechanics. A combined experimental and theoretical study of fatigue crack growth in asphalt concrete material had been made at Hong Kong Road Research Laboratory (HKRRL). Fatigue crack growth rates were measured and related damage, such as deterioration of stiffness modulus, was recorded. The data obtained were used to develop micro-damage models to describe crack growth in asphalt concrete materials. To illustrate crack grown of the asphalt concrete materials under traffic loading in the wearing course and predict flexible pavement service life, a three-dimensional finite element analysis, using micro-damage models was carried out.

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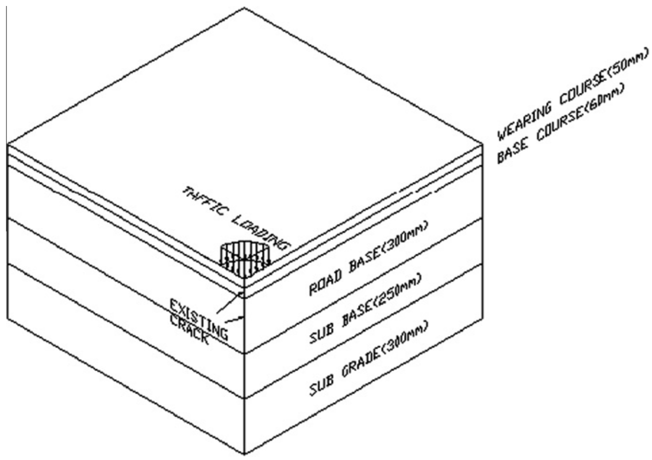


**Fig. 1.** Multi-layered pavement structures.

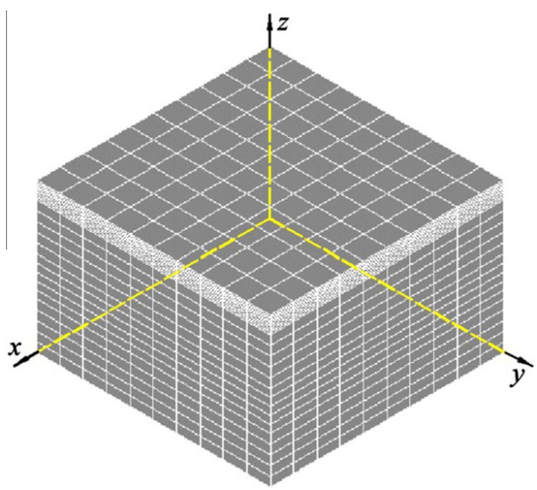


**Fig. 2.** Finite element meshing.

## 2. Features of the finite element model

### 2.1. Model geometry

Conventional flexible pavements consist of multi-layered structure [14], i.e. surface (wearing course), base course and sub-base on a sub-grade. As shown in Fig. 1, pavement structure is modeled as multi-layered system, of which typical material stiffness and layer thicknesses of pavement in Hong Kong is used [15].

The first step in finite element analysis is to create the finite element mesh. Three factors control the finite element mesh geometry:

1. Pavement geometry, which control the general size of the finite element mesh.
2. Load configuration, such as distance between wheels and axles.
3. Degree of detail, i.e. locations where pavement response parameters will be predicted.

In general, finite element mesh dimensions have to be small enough to allow detailed analysis of the pavement section. However, smaller mesh dimensions increase the number of element. As a result, memory and computational time increase. On the other hand, a coarse finite element mesh prevents detailed analysis. A compromise is to use a fine finite element mesh where a detailed analysis in wearing course and base course is conducted while using a coarse mesh elsewhere. The finite element mesh presented in Fig. 2 has 14,670 elements. This large number of elements is used to ensure reasonable representation of the interaction of pavement structure under dynamic loads. Adhesion between each layer is considered as a function of friction and normal pressure on the layers.

### 2.2. Boundary conditions

Boundary conditions for the finite element model have a significant influence on the predicted response of pavement structure. Therefore, potential boundary conditions for pavements need to be considered.

- Edges parallel to the traffic direction ($Y$ axis). Flexible pavements could have one of the three typical cross section geometries shown in Fig. 3. At the pavement edge, two forces exist between the pavement edge and adjacent soil: vertical friction ($F$) and lateral passive pressure ($P$). The friction force ($F$) depends on relative movement, coefficient of friction and the lateral passive pressure from the adjacent soil. Lateral passive pressure ($P$) depends on soil type and weight of the soil expected to affect the pavement. For the configuration number "a" in Fig. 3, the soil wedge is small and both force ($F$ and $P$) can be neglected. In this case the pavement edge can be assumed to be free to move laterally and vertically. Lateral and vertical forces for configuration "b" and "c" may be significant. Both the friction force and the passive pressure are included in the 3D-FEM analysis.
- Edges perpendicular to the traffic direction ($X$ axis). The analysis model should represent adequate length to reduce any edge effect error. However, analysis of an extended length increases the size of the problem and the time for analysis. An evaluation of section length was conducted with lengths from 5 m to 30 m. For section with length greater than 10 m, no significant effect on the pavement response was found. The length of various sections included in this study was 15 m and the load was applied to the middle of these sections.

### 2.3. Material properties

Flexible pavement materials are divided in into three groups: bituminous mixtures, granular materials and cohesive soils. The actual material behavior for each group is considered.

Bituminous mixtures, wearing course, base course and road base, are modeled as a nonlinear visco-elastic material under different load levels and temperatures [16,17]. The dependent properties of bituminous mixtures are represented by dynamic stiffness modulus under different load levels and temperatures base on the ITFT and ITSM testing conducted in Hong Kong Road Research Laboratory (see Tables 1 and 2).

Granular materials, sub-base and sub-grade, are modeled using the linear elastic model including modulus of elasticity, Poisson's ratio, damping coefficient and bulk density.

### 2.4. Loading cycles

The 3-D finite element analysis can be used to simulate traffic loads under different vehicle speeds. At a speed less than 20 km/h, a truncated sawtooth load function is used while a step load function is used for speeds greater than 20 km/h. Fig. 4 shows the truncated sawtooth load cycle used in the analysis.

The load cycle begins with a load magnitude equal to zero at time $T_0$. After time $T_0$, the load is increased linearly to a maximum value at time $T_1$. The load magnitude remains constant between