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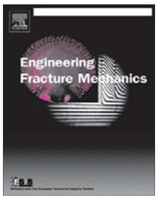

Cracked asphalt pavement under traffic loading – A 3D finite element analysis

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ABSTRACT

An asphalt pavement containing a transverse top-down crack is investigated under traffic loading using 3D finite element analysis. The stress intensity factors (SIFs) and the *T*-stress are calculated for different distances between the crack and the vehicle wheels. It is found that all the three Modes (I, II and III) are present in the crack deformation. The signs and magnitudes of K_{I}, K_{II}, K_{III} and T are significantly dependent on the location of the vehicle wheels with respect to the crack plane. The magnitude of *T*-stress is considerable, if compared to the stress intensity factors, when one of the wheels is very close to the crack plane.

1. Introduction

A huge amount of money is annually spent for the design, construction and maintenance of asphalt pavements [1,2] particularly in the countries having large networks of roads and highways. Cracking is a common mode of deterioration and one of the main causes for the overall failure in asphalt pavement of roads and highways, especially in the cold regions [3–5]. Under subzero and very low temperatures, asphalt pavements often behave as a brittle material and, hence, the risk of sudden fracture from pre-existing cracks in the pavement increases. For such conditions, the stress intensity factors can be used as fundamental parameters in order to characterize the pavement failure due to brittle fracture or fatigue crack growth. Top-down cracks in the surface of asphalt pavements initiate due to daily or seasonal cyclic thermal loads and then extend primarily because of mechanical traffic loading, causing a noticeable increase in the maintenance and rehabilitation cost of pavement [6]. Since cracking of asphalt layers is inevitable, the investigation of crack growth behavior in asphalt pavements is important for estimating the suitable rehabilitation time of pavements and service capability of the roads and highways.

There have been some experimental and numerical studies for investigating the crack growth behavior of asphalt pavements. For example, the fracture resistance of various asphalt mixtures has been investigated experimentally and numerically by Molennar and coworkers [7–9] using different test specimens such as the semi-circular bend (SCB) specimen, the edge cracked rectangular beam specimen subjected to four-point loading, and the center crack plate under tension. Chen et al. [10] also employed the SCB specimen to study the effect of temperature on the tensile strength and fracture toughness of asphalt materials. Other researchers have also investigated the crack growth in asphalt materials using different test configurations such as the rectangular and disc shape compact-tension specimens [11,12], three-point bend beam specimen [13–15] and the modified indirect tensile disc specimen [16].

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Nomenclature

a	depth of rectangular crack
D	transverse distance between the vehicle center and the crack plane
d	half length between front wheels
E	Young's modulus
HMA	hot mix asphalt
K_{I}	Mode I stress intensity factor
K_{II}	Mode II stress intensity factor
K_{III}	Mode III stress intensity factor
$K_{\mathrm{shear\ eff}}$	effective shear stress intensity factor
L	longitudinal distance between the vehicle center and the crack plane
l	half length between the front and rear wheels
P	weight of vehicle
SCB	semi-circular bend specimen
SIF	stress intensity factor
T	T-stress
t	thickness of asphalt pavement layers
w	width of rectangular crack

Greek symbols

ν	Poisson's ratio

In most of the mentioned research studies, fracture of asphalt material has been investigated only under pure Mode I or tensile loads. In practice since the cracks in the asphalt pavement can initiate in various locations and orientations with respect to the traffic direction, the crack growth may occur in a mixed mode manner. In other words, most of the cracks in the surface of the asphalt layer usually experience a combined opening-sliding deformation due to tensile-shear loads. A review of the literature indicates that shear mode or mixed mode (tension-shear) fracture behavior of cracked asphalt pavements has received little attention for the top-down cracks. Among the few available investigations in this area, Buttlar and Braham [17] studied the Mode II or shear mode fracture resistance of an asphalt material experimentally using the beam specimen subjected to anti-symmetric four-point loading. Artamendi and Khalid [18] have also conducted very limited mixed Modes I/II fracture experiments on asphalt materials. On the other hand, most of the research studies related to the fracture behavior of asphalt materials have mainly focused on the laboratory test samples, whereas the fracture behavior of real road pavements in the presence of a crack has not been investigated in detail.

As is well known, one of the main causes of crack growth in pavements is traffic loading [19]. Hence, a cracked asphalt layer is investigated in this paper using numerous 3D finite element analyses under different traffic loading conditions. It is shown that the analyzed cracked asphalt pavement is generally subjected to mixed mode loading, and all the three Modes I, II and III can be significantly present in the flawed asphalt layer depending on the location of the applied loads (induced from the wheels) with respect to the crack plane.

2. Description of crack in asphalt pavement

Asphalt pavements which are used for roads and highways often consist of four main layers (Fig. 1) namely (i) asphalt concrete layer (ii) base layer, (iii) sub-base layer and (iv) sub-grade or soil layer (listed from top to bottom). These layers are usually made of a mixture of bitumen and fine or coarse aggregates. Although several types of cracks can be found in an asphalt pavement, the aim of this research is to study the behavior of a top-down crack that exists in the surface of the asphaltic upper layer. The crack plane is assumed to be perpendicular to the traffic direction and, therefore, the crack can be called the top-down transverse crack. The top layer is usually made of hot mix asphalt (HMA) and its thickness ranges between 10 and 20 cm. Top-down cracks in the asphalt surface layer often initiate because of severe aging of the HMA near the surface or due to low cycle thermal fatigue. They may then propagate due to tensile and shear stresses induced by the vehicle wheels.

Indeed, the experimental observations show that once a top-down crack takes shape normal to the free surface of the asphalt layer, its crack front propagates both normal and parallel to the asphalt surface due to the traffic loads. Since the thickness of upper layer is much less than its width, the propagation of crack parallel to the top surface should be faster than its downward propagation through the more confined asphalt material. Therefore, the shape of a well-developed crack can be roughly simulated by a wide but relatively shallow crack of rectangular shape with round bottom corners. Fig. 1 shows schematically a 3-dimensional description of different layers of an asphalt pavement and a rectangular transverse surface crack (with respect to the traffic direction) initiated from the surface of the upper layer. Fig. 1b shows the side view section of the crack with width w significantly larger than its depth a.