Numerical Simulation of Fracture at Asphalt Mastic Materials
Yassine El Haloui, Mohammed El Omari, Joseph Absi, Fateh Fakhari Tehrani

To cite this version:

Yassine El Haloui, Mohammed El Omari, Joseph Absi, Fateh Fakhari Tehrani. Numerical Simulation of Fracture at Asphalt Mastic Materials. The 3rd International Conference on Optimization and Applications (ICOA 2017), Apr 2017, Meknès, Morocco. hal-01874960

HAL Id: hal-01874960
https://hal.science/hal-01874960
Submitted on 15 Sep 2018

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L’archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d’enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.
Numerical Simulation of Fracture at Asphalt Mastic Materials

Y. EL Haloui and M. Elomari
LAEPT-URAC 28, University Cadi Ayyad, Faculty of Science Semlalia, BP 2390, Marrakech, Morocco
Email: yassine.elhaloui@edu.uca.ac.ma
Email: elomari@uca.ac.ma

J. Absi
SPCTS, Centre Européen de la Céramique, 12 Rue Atlantis 87068 LIMOGES Cedex, France.
Email: joseph.absi@unilim.fr

F. Fakhari Tehrani
Centre Universitaire de Génie Civil Université de Limoges, boulevard Jacques Derche, Egletons, France.
Email: fateh.fakhari-tehrani@unilim.fr

Abstract—In this paper, numerical simulations have been conducted to investigate how damage initiates and propagates at mastic materials. Mastic is known as the matrix component of asphalt concrete. The 2D specimen digital model has been created by using a layer of mastic material which is inserted between two coarse aggregate. Cohesive elements have been inserted into mastic to simulate crack initiation and propagation. The effects of loading and stiffness modulus will be investigated. Many important conclusions will be given.

I. INTRODUCTION

Asphalt concretes (AC) are complex biphasic materials composed of asphalt binder, fine and coarse aggregate. Fine aggregate are mixed with asphalt binder to formulate the mastic [1], [2], [3]. In general, fracture occurs mostly at mastic and at the interface between coarse aggregate and mastic [4], [5]. Recently, many researchers have been concentrating on the simulation of damage and fracture within AC. Song et al [4] and Yin et al [5] investigated about fracture by simulation of the three point bending beam, in this studies, cohesive element approach was used.

In this paper, 2D fracture simulation at mastic will be modelled. The RVE is represented as a layer of mastic which is placed between two coarse aggregate. Crack initiation and propagation within mastic will be shown. The effects of the loading rate and stiffness modulus will be investigated.

The objectives of this work are:

• Numerical simulations of damage initiation and fracture within mastic.
• Evaluating the impact of loading on the crack propagation.
• Identifying influence of stiffness modulus on damage initiation and evolution.

A. Numerical model description

1) Cohesive element approach: Cohesive element approach is a numerical method that can be used to simulate cohesive damage at mastic. Cohesive element behaviour is shown in Figure 1, cohesive element behaves elastically until the maximum stress criterion is reached (Initiation of damage).

The elastic behaviour can be written as described in equation (1) [6].

\[
\begin{bmatrix}
\tau_n \\
\tau_s \\
\tau_t
\end{bmatrix} =
\begin{bmatrix}
K_{nn} & 0 & 0 \\
0 & K_{ss} & 0 \\
0 & 0 & K_{tt}
\end{bmatrix}
\begin{bmatrix}
\delta_n \\
\delta_s \\
\delta_t
\end{bmatrix}
\]

(1)

Where \( \tau_n, \tau_s \) and \( \tau_t \) are the normal and two shear traction stresses respectively. \( K_{nn} \) is the stiffness in the normal compressive direction, \( K_{ss} \) is the stiffness in the first shear direction and \( K_{tt} \) is the stiffness in the second shear direction.

After damage initiates, the stiffness of mastic will be

\[
Max\left\{ \frac{\tau_n}{\tau_n^0}; \frac{\tau_s}{\tau_s^0}; \frac{\tau_t}{\tau_t^0} \right\} = 1
\]

(3)

Where \( \tau_n^0, \tau_s^0 \) and \( \tau_t^0 \) are the strength toward normal, first and second shear directions respectively.

After damage initiates, the stiffness of mastic will be
Proceeding of The International Conference on Optimization and Applications (ICOA2017)

degraded. Stiffness degradation ratio is evaluated by a scalar variable named D. D varies from 0 to 1. When D equals 1, the stiffness of mastic is totally degraded. The stress components at the stiffness degradation are given in equations 4, 5 and 6 as:

\[
\tau_n = (1 - D) \tau_n (4)
\]

\[
\tau_s = (1 - D) \tau_s (5)
\]

\[
\tau_t = (1 - D) \tau_t (6)
\]

Where \(\tau_n\), \(\tau_s\) and \(\tau_t\) are the stress components predicted by the elastic traction-separation behaviour for the current strains without damage [6].

After degradation of the stiffness of mastic, fracture will occur. The fracture energy can be expressed as below in equation 7:

\[
\phi = \frac{1}{2} \tau_0 (n,s,t) \delta_f (n,s,t) (7)
\]

Where \(\delta_f (n,s,t)\) is the separation value at fracture.

2) Cohesive elements insertion: Cohesive elements are inserted between the original solid elements of mastic. The method of insertion can be found in [7]. Figure 2 illustrates the cohesive element insertion steps. The first step is to mesh the layer of mastic on ABAQUS, triangle finite elements for 2D specimen is used (figure 2a). The second step is to modify the initial mesh, every common node between two or more solid elements is duplicated. Moreover, cohesive elements with zero thickness are inserted between faces of neighbouring solid elements and joining them together (figure 2b).

3) Numerical model: The 2D numerical model chosen for this paper is represented in Figure 3. The model is composed of two coarse aggregate and a layer of mastic which is inserted between them. The 2D specimen with dimensions of 40 mm × 25 mm. The dimensions of each coarse aggregate is 40 mm × 10 mm. The mastic is with dimensions of 40 mm × 5 mm.

In general, aggregate behaves elastically. While mastic is thermal-sensitive material, it is viscous at higher temperature, visco-elastic at medium temperature and elastic at lower temperature respectively [1], [2]. Fracture tests of asphalt concrete were conducted at –10°C by H. Kim et al [8], the test results are given in table I.

<table>
<thead>
<tr>
<th>TABLE I: The input parameters of the numerical simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregate</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Elastic modulus</td>
</tr>
<tr>
<td>Initial stiffness</td>
</tr>
<tr>
<td>Fracture energy</td>
</tr>
<tr>
<td>Tensile strength</td>
</tr>
</tbody>
</table>

Abaqus software is used to carry out the finite element analysis. The quasi-static simulations are considered with a step time of 1 s. The displacement is applied at the top surface of the upper aggregate, it increases linearly from 0 to 0.5 mm during the time of step. Vertical and horizontal displacements at the bottom surface of the model are constrained.

The free meshing method is considered. An overall mesh
size of 0.5 \text{mm} is used to generate the mesh; CPS3 is a 3-node linear plane stress triangle finite element, it is used to mesh the numerical model (Two aggregate and the mastic). COH2D4 is a 4-node two-dimensional finite element used to define the cohesive elements which are inserted between solid elements of mastic. Illustration of the numerical model, loading and boundary condition are shown in figure 3. Mesh configuration of the numerical model is presented in figure 4.

**B. Results and discussion**

The maximum nominal stress criterion (Equation 3) is evaluated by MAXSCRT (Output of ABAQUS varies from 0 to 1). If MAXSCRT is inferior than 1, damage will not initiate, whereas damage is assumed to begin when MAXSCRT achieves 1.

The scalar damage variable D is evaluated by SDEG (Output of ABAQUS varies from 0 to 1). For example, if SDEG=0.2, 20% of the stiffness of mastic will degrade. Fracture is assumed to begin when SDEG achieves 1.

1) *Effect of loading:* In this section, the effect of loading on fracture will be shown. The applied displacement increases linearly from 0 to 0.5 \text{mm} during the step time of 1 \text{s}. Cracks initiation and propagation are observed in 2D model of AC specimen with upon increment of loading. The detailed crack initiation and evolution are presented in figure 5, in this figure, only mastic bloc is shown without the aggregate and the mastic size scale is increased to visualize the cracking paths. Figs 5a, 5b, 5c and 5d show the status of the 2D digital specimen at step time of 0, 0.2, 0.3 and 1 \text{s} respectively. It can be seen that two cracks are initiated and propagated as the loading increases. The first crack is initiated at the top-left region of mastic, it propagates horizontally from the left side to the right one of specimen. However, the second crack is created at the bottom-right region of mastic and propagates horizontally from the right side to the left one for a distance almost equals 10 \text{mm}.

MAXSCRT (Damage criterion) and SDEG (Stiffness degradation) for two cohesive elements are plotted in figure 6. On the one hand, the first cohesive element is where the first crack tip appeared (top-left region of mastic). On the other hand, the second cohesive element is where the crack tip of the first crack ended (top-right region of mastic). For the first cohesive element, damage initiates at t=0.01 \text{s} (MAXSCRT=1). In the meantime, SDEG value exceeds 0 and achieves 1 at the time t=0.1 \text{s}. For the second cohesive element, damage starts at t=0.17 \text{s} and SDEG value exceeds 0 and achieves 0.9997 at t=1 \text{s}. The second cohesive element has not been fractured yet (SDEG is still less than 1). Fracture might occur if the loading rate exceeds 0.5\text{mm}.
2) Effect of stiffness modulus: One of the important parameters affecting the fracture behavior is the stiffness modulus of mastic. The stiffness modulus $K$ used in the previous case is $18.2\ GPa/mm$, to investigate how $K$ affects the overall fracture behavior, 50% of $K$, K and 150% of $K$ are assigned to the mastic material at the same loading condition ($0.5\ mm$). Figure 7 illustrates the crack paths at mastic. Figures 7a and 7b show the crack paths of stiffness of 9100 MPa (50% of $K$) and 27300 MPa (150% of $K$) respectively. For stiffness of 9100 MPa, it reveals that only one crack appears and the mastic is divided to two parts. For stiffness of 27300 MPa, it reveals that the crack paths are almost identical to the crack path found in the case of stiffness equals $K$. The difference between the two crack paths is that in the case of the second crack (crack at the bottom-right region), there is one more cohesive element which is separated in the case of stiffness which equals 27300 MPa (see figs 7b and 5d).

II. CONCLUSION

The present work presents numerical simulations of fracture at asphalt materials using cohesive element method. Cohesive elements are inserted into mastic to inquire into cracking initiation and propagation. Based on the above results, the following conclusions are drawn:

- Cracks were initiated and propagated at mastic with upon increment of loading.
- The stiffness modulus value can influence the cracking paths at mastic.

REFERENCES