Construction and Building Materials 49 (2013) 536–546

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Identifying damage in asphalt matrix materials surrounding an aggregate particle

Mohammad I. Hossain *, Rafiqul A. Tarefder [1]

Department of Civil Engineering, The University of New Mexico, USA

HIGHLIGHTS

- Cohesive damage is higher than adhesive damage under both dry and wet conditions.
- Matrix–aggregate interface is the weakest region.
- Cohesive damage propagates towards interface and initiate adhesive damage.
- Thicker matrix on aggregate prevents adhesive damage at the interface.

ARTICLE INFO

Article history:
Received 2 June 2013
Received in revised form 23 August 2013
Accepted 29 August 2013
Available online 23 September 2013

Keywords:
Damage
Asphalt concrete
Matrix
Finite Element Method
Cohesive
Adhesive

ABSTRACT

In this study, damage in asphalt matrix surrounding an aggregate particle is modeled in ABAQUS, which is commercially available finite element software. Damage is identified by damage location, magnitude, and percentage damaged area in matrix under dry and wet conditions. Normal and shear stiffness of matrix material are determined in the laboratory. Model simulations are run considering thin and thick layers of matrix, two applied deformations considering tire pressure, and three deformation intensity patterns considering application time of the tire pressure. The results indicate that damage initiates at the surface and propagates towards the matrix–aggregate interface. Damage in the wet conditioned samples is higher than those in dry samples, which is expected, because wet samples have lower stiffness and strength than dry samples. In both dry and wet conditions, more damage occurred in the vicinity of the surface (cohesive damage) that in the interface (adhesive damage). Cohesive damage is higher than adhesive damage but matrix–aggregate interface is the weakest region since damage propagates towards interface without causing significant damage inside the matrix other than top surface of matrix. However, thicker matrix prevents adhesive damage by protecting damage progression towards interface. Damage increases while deformation magnitude and application time increases. The worst damage scenario observed for thin matrix with 1.27 mm (0.057 in.) deformation and for rectangular pattern; about 16.67% matrix–aggregate interface and 30.30% of the vicinity of surface area are damaged under wet condition.

1. Introduction

Asphalt Concrete (AC) can be defined as asphalt coated coarse aggregate particles surrounded by mastic and matrix materials. Mastic is a mixture of fines (materials passing #200 sieve) and asphalt binders. Matrix is a mixture of asphalt binder with fine aggregates passing through a #4 (4.75 mm) sieve and retained on a #200 sieve [1–4]. Damage due to moisture in AC occurs mostly in the mastic or matrix or interface of the materials [5]. Most researchers agree that damage due to moisture inside an aggregate particle is limited. Rather, most of the moisture damage occurs in mastic and matrix materials. This study focuses only on the matrix damage due to moisture.

Cohesive and adhesive damage are two major reasons of AC damage [6–10]. The phenomena of adhesive and cohesive damage are shown schematically in Fig. 1. Fig. 1a shows a fresh sample of AC, which is not subjected to any damage. Fig. 1b shows loss of bonding within the asphalt binder or mastic or matrix (cohesive)

Abbreviations: AC, Asphalt Concrete; FEM, Finite Element Method; VEPCD, Visco-Elastic–Plastic Continuum Damage; DSC, Disturb State Concept; MAXSCRT, Maximum Stress Criteria; SDEG, Strength Degradation.

* Corresponding author. Address: Centennial Engineering Building, Room-2009, University of New Mexico, 210 University Blvd. NE, Albuquerque, NM 87106, USA. Tel.: +1 505 550 6264; fax: +1 505 277 1988.

E-mail addresses: mhossain@unm.edu (M.I. Hossain), tarefder@unm.edu (R.A. Tarefder).

[1] Address: Centennial Engineering Building, Room-3054, 210 University Blvd. NE, Albuquerque, NM 87106, USA. Tel.: +1 505 277 6083; fax: +1 505 277 1988.

0950-0618/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.conbuildmat.2013.08.083

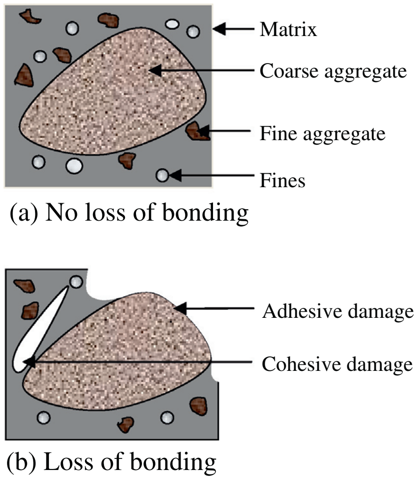

Fig. 1. Schematic of adhesive and cohesive damage in AC.

and at the matrix–aggregate or mastic–aggregate interface (adhesive). Few studies are considered in the past to understand the evolution and progression of matrix damage under dry and wet conditions [1,3,11].

Damage initiates at molecular scale but it is clearly visible at mesoscale, a full scale pavement. Although the previous studies show the severity of damage due to moisture condition but this study is done to understand how damage initiates in matrix materials (cohesive damage) and then move towards matrix aggregate interface (adhesive damage) and quantify this damage for a small scale considering variability of AC. It is believed that, the understanding of damage in small scale will help to improve the mix design procedure, select appropriate construction materials, application of additives, better material design to prevent damage and many more. In this study, damage in a system of aggregate coated by matrix, considered as small scale AC, is studied. Total damage is characterized as cohesive and adhesive damage as described in Fig. 1. To identify initiation and location of damage, the damage is evaluated using damage evaluation criteria defined by maximum nominal stress criteria. Maximum stress criteria is defined as, damage initiates within a material when it reaches to maximum strength under loading condition [12–15].

1.1. Objectives

The objectives of this research work are,

(1) Identify damage and categorize it into the adhesive and cohesive damage in matrix material of AC under dry and wet conditions.
(2) Evaluate the effects of moisture in adhesive and cohesive damage initiation and propagation.
(3) Quantification of adhesive and cohesive damage in the matrix materials.

1.2. Methodology

Maximum stress criteria is used to determine adhesive and cohesive damage by applying Finite Element Method (FEM) modeling. Commercial software ABAQUS is used as a tool of FEM. Laboratory tests are performed on matrix material under dry and wet conditions to determine the FEM damage model inputs. The initiation and progression of the adhesive and cohesive damage of matrix coated an aggregate particles are evaluated and quantified considering two different matrix thicknesses, two deformation magnitudes representing tire pressure on AC, and three deformation intensity patterns representing deformation application time of tire pressure on AC.

1.3. Damage modeling of AC

Concept of damage mechanics is introduced in early 1920 but a major breakthrough is occurred in late 1950 by Kachanov [16]. Damage in material due to environmental degradation such as presence of moisture and damage in concrete materials due to non-homogeneous material is introduced [17]. It is mentioned that geo-materials and polymers changes their mechanical properties under the influence of environment even in the absence of stress. Also concrete like materials have weak mechanical resistant due to non-homogeneity.

Damage in AC is studied for decades. In early 1990, damage in visco-elastic materials in terms of accumulated viscous strain is described [18]. Later on, visco-elastic damage model is applied on AC [19]. This model is modified and a Visco-Elastic–Plastic Continuum Damage (VEPCD) model is developed to study initiation and accumulation of micro-cracking due to material damage and to study damage progression [20]. FEM is implemented using VEPCD and simulation of damage growth due to accumulation of viscous strain under fatigue loading is performed [21]. According to authors knowledge, VEPCD does not identified cohesive and adhesive damage in AC. Desai defined disturbance as a damage to measure the translation, rotation and micro-structural changes within AC materials [20]. Desai's Disturb State Constitutive (DSC) model is not used to characterize stiffness degradation of matrix or disturbance in mastic or matrix due to moisture.

Several Finite Element Method (FEM) based damage models are developed to characterize linear viscoelastic and visco-elastic–plastic materials [22–24]. Most of the models used VEPCD or modified VEPCD with user defined constitutive equation implemented in FEM model for full scale pavement or cylindrical core specimens. Damage due to accumulation of visco-elastic and visco-plastic strain is shown for different temperature under loading conditions. Also, maximum stress criteria is implemented as cohesive zone modeling for predicting multi-scale damage model by FEM [25]. An aggregate surrounded by asphalt is considered as small scale and a full scale AC pavement consists of several aggregates is considered as large scale model. Average stress and strain in the FEM models are computed and compared for both undamaged and damaged conditions. Cohesive zone model is also implemented by FEM for cylindrical AC sample [26]. Only stress and strain relationships are computed for different strain rates.

Many studies are done to identify damage under dry and wet conditions in AC [10,27–32]. Most of the studies evaluate damage in AC by laboratory measurements. Even though both laboratory investigations and FEM model studies are agreed with the concept of adhesive and cohesive damage but very few of them able to identified and evaluated those damage into FEM models. Most of the studies emphasized on the total damage of AC. Also, none of them has able to include and evaluate both adhesive and cohesive damage in a single FEM model. In addition, very few studies conducted FEM analysis under both dry and wet conditions. Initiation, progression, and quantification of the adhesive and cohesive damage using maximum stress criteria in matrix under wet and dry conditions are not performed yet.

1.4. Damage law for cohesive elements

Cohesive element damage law is used in this study to define matrix damage. Cohesive law is defined by a monotonically increasing traction-separation load up to a critical point followed by a monotonically decreasing load or softening curve [33]. The