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Numerical Computation of Coupled Adhesive and Cohesive Damages in Asphalt Concrete

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Abstract: In this study, coupled adhesive and cohesive damages in asphalt concrete (AC) are computed using finite element method (FEM) modeling under dry and wet conditions. FEM model consists of an aggregate coated with mastic and surrounded by matrix materials, is developed by using ABAQUS. Laboratory tests were conducted on matrix and mastic materials under both dry and wet conditions to evaluate FEM model. Damage inside matrix material is considered as cohesive damage and inside mastic material is considered as adhesive damage. FEM model is simulated by static and one cycle of dynamic applied deformation. Results indicate that, cohesive damage is observed under both dry and wet conditions for dynamic load but more matrix areas are damaged under wet conditions than dry conditions. On the other hand, adhesive damage is higher under dry condition but cohesive damage is higher under wet condition for static loading condition. Both stiffness and strength of mastic and matrix materials are important factors to initiation and progression of damage in AC. Cohesive damage initiates at the surface of matrix but propagates towards mastic material and initiate adhesive damage since stiffness and strength of mastic material is lower than matrix material.

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***Key words**: Asphalt concrete; Cohesive; Adhesive; Damage; Finite element method.*

Introduction

Asphalt Concrete (AC) is a geological composite material that consists of asphalt binder, aggregate, and fines. Asphalt binder is a viscoelastic material and aggregate and fines are elastic brittle materials, but the combination of these materials will produce a visco-elastic-plastic composite material. Severe strength degradation is observed in AC due to environmental conditions such as atmospheric oxygen and moisture. AC pavements have voids inside the structure while it compacts by compactor. Atmospheric oxygen interacts with asphalt binder and hardens the material, and this phenomenon is known as aging. On the other hand, moisture diffuses into asphalt binder and infiltrates through asphalt binder-aggregate interface and saturates aggregate. Moisture reacts with asphalt binder and changes its molecular structure and causes damage. A combination of aging and mositure-induced damage is very complex phenomena. In this study, a small scale AC sample is modeled to understand the moisture-induced damage only.

In AC, the fines are defined by the material passing through number 200 sieve (0.075 mm.). Asphalt binder creates a thin film or coating around the aggregate particles and fines. Indeed, the fines become trapped inside an asphalt binder film, which is also known as mastic [1]. The mixture of asphalt binder and aggregate passing through number 4 sieve (4.75 mm.) and retaining on number 200 sieve is called matrix [2]. Furthermore, matrix can be divided into coarse matrix and fine matrix; coarse matrix is defined as fine aggregate passing number 4 sieve and retained on number 10 sieve (2.0 mm.) and fine matrix defined as passing number 10 sieve and retained on number 200 sieve [3]. Thus AC can be defined as coarse aggregate (retain on number 4 sieve) coated with mastic material and surrounded by matrix material.

Damages in AC can be attributed to two primary mechanisms, namely, the loss of adhesion, and the loss of cohesion. Loss of adhesion, also called stripping, is caused by breaking of the adhesive bonds between the aggregate surface and the mastic primary due to the action of water. Loss of cohesion is caused by the softening or breaking of cohesive bonds within the matrix or mastic due to the action of water. Fig. 1 shows a schematic diagram of adhesive and cohesive damage in AC. In Fig. 1(a), Coarse aggregates are coated by mastic material and surrounded by matrix material and without any damage, but in Fig. 1(b), part of the mastic and the matrix coatings over aggregate are worn out and inside the matrix the material is torn down. The worn out phenomenon in defined as adhesive damage and torn down phenomenon is defined as cohesive damage.

Objectives

The objectives of this study are to evaluate coupled adhesive and cohesive damages in AC under static and dynamic loads. An aggregate coated with mastic material and surrounded by matrix material is evaluated under wet and dry conditions after numerical validation of the damage model.

Methodology

Finite Element Method (FEM) modeling technique is adopted to explain the evaluation of damage inside matrix and mastic materials. ABAQUS is used as a tool of FEM. In this study, a simplified approach is considered to define damage due to complex phenomena of damage in AC. According to this study, damage inside the mastic material, which is coated an aggregate, is called

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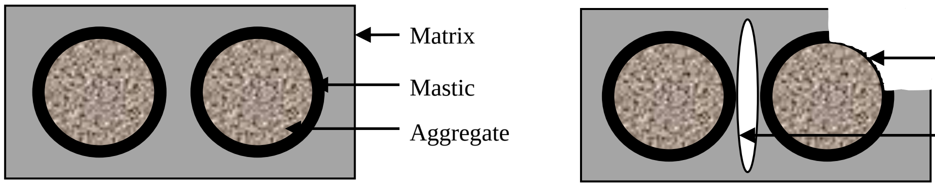


(a) No loss of bonding (b) Loss of bonding

Fig. 1. Schematically Adhesive and Cohesive Damages in Asphalt Concrete.

adhesive damage and damage inside matrix material, which is surrounded aggregate and mastic material, is called cohesive damage. Maximum-stress criteria, which is available in ABAQUS, is selected for damage modeling. Maximum stress criteria is defined as damage initiates inside a material when the material reaches to its ultimate strength [4]. Compressive and shear tests were conducted on matrix materials under dry and wet conditions. Tensile and shear tests were conducted on mastic materials under dry and wet conditions. It has been observed that, upon loading, material, which is under direct load experiences compressive stress and material at the interface location experiences tensile stress due to slipping phenomena at the mastic-aggregate interface. For this reason, matrix material was tested under compression and mastic material was tested under tension.

Introduction to Damage Law

Cohesive element damage law is used in this study to define mastic and 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 [5]. The critical point or highest point or load is known as the damage initiation point. In this study, traction-separation law is applied to cohesive elements. The elastic behavior is defined by an elastic constitutive matrix that relates to the nominal stress and nominal stain in the elements. Nominal stress is defined by the force component divided by the element area at each integration point. Nominal strain is the separation divided by the original thickness at each integration point. The nominal stress vector, σ, consists of three traction components σ_n acting to the pure normal direction, σ_s acting toward the first shear direction and σ_t acting toward second shear direction. The stress vector σ can be express in terms of stiffness tensor E and vector ε,

$$\sigma = \begin{Bmatrix} \sigma_n \\ \sigma_s \\ \sigma_t \end{Bmatrix} = \begin{bmatrix} E_{nn} & E_{ns} & E_{nt} \\ E_{ns} & E_{ss} & E_{st} \\ E_{nt} & E_{st} & E_{tt} \end{bmatrix} \begin{Bmatrix} \varepsilon_n \\ \varepsilon_s \\ \varepsilon_t \end{Bmatrix} = E\varepsilon \tag{1}$$

where E_{nn} is the stiffness in the pure normal mode, E_{ss} is the stiffness in the first shear direction and E_{tt} is the stiffness in the second shear direction. The diagonal terms of the stiffness matrix are stiffness in the coupled mode (coupling between normal and shear mode). Damage is assumed to initiate when the maximum nominal stress ratio reaches a value of one. The maximum nominal stress ratio is defined by Eq. (2) below,

$$max\left\{\frac{\langle\sigma_n\rangle}{\sigma_n^0}, \frac{\sigma_s}{\sigma_s^0}, \frac{\sigma_t}{\sigma_t^0}\right\} = 1 \tag{2}$$

where σ_n^0 is the nominal strength towards normal direction of matrix, σ_s^0 is the nominal shear strength toward first direction and σ_t^0 is the nominal shear strength toward the second direction measured in the laboratory. In this study, only compressive strength and shear strength to the first direction of the matrix material and tensile strength and shear strength towards first direction of mastic material were measured in the laboratory. The tests were done under both dry and wet conditions. Also, two dimensional FEM model is considered for identifying damage. For this reason, the second shear strength parameter is not required and Eq. (2) becomes,

$$max\left\{\frac{\langle\sigma_n\rangle}{\sigma_n^0}, \frac{\sigma_s}{\sigma_s^0}\right\} = 1 \tag{3}$$

The symbol $\langle\ \rangle$ is known as Macaulay bracket. Macaulay brackets are used to signify that a pure compressive deformation or stress state does not initiate damage.

Laboratory Investigations

Tests on Matrix Material

Asphalt mix was collected from a local plant, in cooperation with the New Mexico Department of Transportation (NMDOT). The loose mix was separated by sieving. Loose mix passing through number 16 sieve (1.19 mm) and retained on number 200 sieve was collected as matrix material. Cylindrical samples of height 69.85 mm (2.75 in.) and 35.31 mm (1.39 in.) diameter were compacted to a target void ratio of 4.0 ± 0.5%. For wet conditioning, before testing, the samples were soaked for 48-hours under water at room temperature and subjected to a vacuum pressure of 4.0 MPa for half an hour. Three dry and three wet cylindrical matrix samples were uniaxially loaded to failure under strain-controlled mode. The tests were conducted at ambient temperature. A loading rate of 1.27 mm/min (0.5 in/min) was used. Also, three dry and three wet samples were compacted in a shear box and subjected to shear failure with a loading rate of 1.27 mm/min (0.5 in./min). Average of three samples' results from compression and shear tests are summarized in Table 1. Stiffness E-value is determined by measuring the slope of secant modulus. Secant modulus is defined as slope connecting origin to 50% of maximum strength of material [6]. Secant modulus is used because non-linear elastic behavior is

Table 1. Laboratory Test Results of Matrix Material Under Dry and Wet Conditions.

	Test Type	Ultimate Strength	E-value
Dry	Compression	2.61 [MPa] (379 [psi])	192.72 [MPa] (27,952 [psi])
	Shear	0.81 [MPa] (118 [psi])	147.64 [MPa] (21,413 [psi])
Wet	Compression	2.02 [MPa] (293 [psi])	129.44 [MPa] (18,773 [psi])
	Shear	0.56 [MPa] (81 [psi])	139.10 [MPa] (20,174 [psi])

Table 2. Laboratory Test Results of Mastic Material Under Dry and Wet Conditions.

	Test type	Ultimate strength	E-value
Dry	Tension	0.61 [MPa] (88 [psi])	145.91 [MPa] (21,163 [psi])
	Shear	0.38 [MPa] (55 [psi])	124.02 [MPa] (17,987 [psi])
Wet	Tension	0.26 [MPa] (38 [psi])	76.70 [MPa] (11,124 [psi])
	Shear	0.69 [MPa] (100 [psi])	26.87 [MPa] (3,897 [psi])

observed under dry and wet conditions.

Tests on Mastic Material

The loose mix collected from NMDOT plant was sieved and the mix passing through number 200 sieve was collected as mastic material. Cylindrical samples were prepared as described in the previous section. Three dry and three wet samples were uniaxially loaded to failure under strain-controlled mode. Similar loading rate was used as it was for the compression test. Average of three samples' results from tension and shear test are summarized in Table 2. Secant modulus is calculated as described in the previous section. It should be noted that under wet conditions the shear strength is higher compared to dry conditions but the E-value is significantly lower. In another study, it has been observed that the roughness of aggregate and mastic material increased due to moisture-conditioned [7]. The reason behind the aggregate volume increases after moisture absorption and in the case of fines, is that due to a higher surface area, the effect of volume increase is significant. While shear force is applied, friction force generates between fines and asphalt binder. Higher roughness in aggregate surface generates higher friction forces at the interface of fines and asphalt binder and causes higher ultimate strength comparing to dry condition.

FEM Model Development

The FEM model is developed using ABAQUS/CAE 6.9-EF1, commercially available software. A two-dimensional idealization of a circular aggregate surrounded by a layer of mastic and matrix materials is considered. Obviously, it can be argued that the circular aggregate is not a true representation of aggregate particles that reside in an AC. A similar argument can be made on the size of the aggregate particle. The fact is, the shape and size of aggregate particle varies significantly in asphalt concrete. Therefore, a study that would consider the effects of the size and shape on the outcomes, that is asphalt cohesion and adhesion can itself be complex, yet doable. For simplicity, the model considered for this study is one quarter of a circular coarse aggregate surrounded by a layer of mastic and matrix materials, as shown in Fig. 2. This suffices the purpose of this study. The radius of the aggregate is assumed to be 19.05 mm. (0.75 in.) based on the nominal maximum size (25.0 mm) of the mix aggregate collect from the plant. A 0.254 mm (0.01 in.) thick mastic and 0.508 mm (0.02 in.) thick matrix is considered.

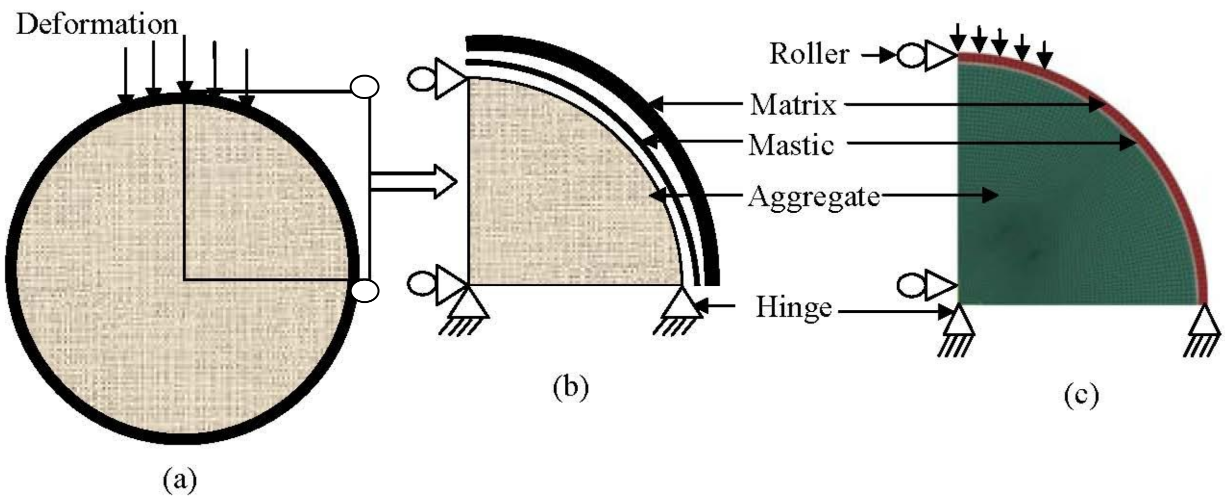


Fig. 2. (a) Schematic of Aggregate Surrounded My Mastic and Matrix Materials (b) Separately Shown Mastic and Matrix Materials (c) FEM Model with Mesh, BC, and Loading Conditions.

Though AC is considered to be visco-elastic-plastic material, matrix and mastic are assumed to behave elastically, based on some previous study. It has been mentioned that AC behaves elastically at low temperatures and viscoelastically at high temperatures [8]. Also, wet AC behaves more elastically compared to dry AC [3]. E-value of aggregate is well established in literature, therefore, laboratory tests were not conducted on aggregate. The E-value of aggregate used in this study is 48.26 GPa (7,000,000 psi) and the Poisson's ratio is 0.20 [9].

The loading and the shape of the FEM model are symmetrical to the vertical axis. The model is restrained for vertical and horizontal movement at the bottom, but only horizontal movement is restrained on the left side. Four noded linear quadrilateral cohesive elements are used to define the mastic and the matrix materials. Linear elements are used since quadratic elements are not available for assigning axi-symmetric cohesive element. Three and four noded linear quadrilateral plane stress elements are used to define the aggregate. Combinations of both three and four noded elements are required due to the circular shape of the aggregate. In ABAQUS, maximum stress criteria required maximum stress in both vertical and shear directions. Since the model is two-dimensional, data from one shear direction is sufficient. The interface between mastic and aggregate, and mastic and matrix are defined as cohesive interaction. The bottom of mastic surface and the top of aggregate surface are selected and the bottom of the matrix surface and the top of the mastic surface is selected to make an interface. FEM model should have interface interaction behavior while model consists of two different materials and in contact.

In the FEM model, instead of applying a load, a specified deformation is applied and stresses are calculated and used to determine damage according to the Eq. (3). Deformation magnitudes 1.45 mm (0.057 in.) is applied on the FEM model. It should be noted that the FEM model can be simulated as load control and deformation control, since the laboratory tests were performed under deformation control, so deformation control is selected to conduct FEM model. The magnitude of the deformation is calculated based on a standard dual tandem wheel on a pavement. It has been observed that a dual tandem wheel of total 889.64 kN (200,000 lb) load produces a 1.45 mm. (0.057 in.) deformation in a 203.02 mm. (8 in.) thick asphalt pavement. Therefore 1.45 mm. (0.057 in.) deformation was considered. Though the applied deformation magnitude could be the worst case scenario because the selected dual tandem load is applicable for aircraft landing gear and the location of the model mastic-matrix coated aggregate is assumed at the surface of AC pavement. For this reason maximum applied deformation is considered on the model.

Static and dynamic deformations are used to evaluate damage. Under static condition, the 1.45 mm. (0.057 in.) deformation increases linearly over 0.1 sec, the phenomenon is also known as ramp loading. Under dynamic condition, one cycle of dynamic deformation is applied with the 1.45 mm. (0.057 in.) peak amplitude. The period of the cycle is 0.1 sec. The peak amplitude is achieved at 0.05 sec and then the unloading is achieved following 0.05 sec. The deformation load is applied in ABAQUS on 10.16 mm. (0.4 in.) length of matrix. Usually, indirect tensile strength of asphalt concrete is determined by subjecting an AC sample diametrically though a 20.32 mm.-25.4 mm. (0.8-1.0 in.) loading strip. Since the model is axi-symmetric, deformation load is applied over 10.16 mm. (0.4 in.) length.

FE Model Varification

A numerical verification is done on a single cohesive element to check how the maximum stress criteria model works in ABAQUS. A 25.4 mm. (1.0 in.) by 25.4 mm. (1.0 in.) square element is restrained horizontally and vertically at the bottom nodes and two 10 lb concentrated loads are applied at the top nodes as shown in Fig. 3(a). Two models are simulated under both dry and wet conditions. Damage model parameters for matrix material as described in Table 1 are used for numerical verification. The results are presented under dry condition in Fig. 3(b) to 3(f). The stresses are given in psi and strain calculated in in/in units. For normal stress and strain, a positive sign indicates tension and a negative sign indicates compression. For shear stress and strain, a positive sign indicates anticlockwise actions about element center and vice versa. The sample calculations under dry conditions are as follows,

$$\begin{Bmatrix}\sigma_2\\ \sigma_{12}\\ 0\end{Bmatrix}=\begin{bmatrix}27952 & 0 & 0\\ 0 & 21413 & 0\\ 0 & 0 & 0\end{bmatrix}\begin{Bmatrix}0.00072\\ 0.00093\\ 0\end{Bmatrix}\Rightarrow\begin{Bmatrix}\sigma_2\\ \sigma_{12}\\ 0\end{Bmatrix}=\begin{Bmatrix}20.12544\\ 19.91409\\ 0\end{Bmatrix};$$

$$max\left\{\frac{20.12544}{379};\frac{19.91409}{118}\right\}\Rightarrow max\{0.053, 0.169\} \qquad (3)$$

$$\Rightarrow MAXSCRT=0.169$$

where σ_2 (*S22* in Fig. 3(b)) is the normal stress and σ_{12} (*S12* in Fig. 3(d)) is the shear stress. According to Fig. 3(b) and (c), the left side of the element is showing tensile stress and the right side of the element showing compressive stress. The concentrated force at the top of the element causes bending towards the right. The anticlockwise shear stress resists the bending movement. Unlike normal stress and strain variation over the element, shear stress and strain shows one single value because there are no variations of shear stress and strain in the element. Though the contour scale shows color variations but the numerical value is same for all colors. According to the calculation, the MAXSCRT value is 0.169, which matches with the value calculated by the ABAQUS as shown in Fig. 3(f). MAXSCRT is the maximum value comparing the normalized normal stress and shear stress. Also, MAXSCRT is a unit with less value since it has the ratio of two stresses.

The stresses calculate in psi unit under wet condition are as follows,

$$\begin{Bmatrix}\sigma_2\\ \sigma_{12}\\ 0\end{Bmatrix}=\begin{bmatrix}18773 & 0 & 0\\ 0 & 20174 & 0\\ 0 & 0 & 0\end{bmatrix}\begin{Bmatrix}0.00107\\ 0.00099\\ 0\end{Bmatrix}\Rightarrow\begin{Bmatrix}\sigma_2\\ \sigma_{12}\\ 0\end{Bmatrix}=\begin{Bmatrix}20.08711\\ 19.97226\\ 0\end{Bmatrix};$$

$$max\left\{\frac{20.08711}{293};\frac{19.97226}{81}\right\}\Rightarrow max\{0.069, 0.247\} \qquad (4)$$

$$\Rightarrow MAXSCRT=0.247$$

Under wet conditions, the MAXSCRT value is 0.247, which matches with the ABAQUS results. By comparing the MAXSCRT values of dry and wet conditions, wet conditions give a higher value

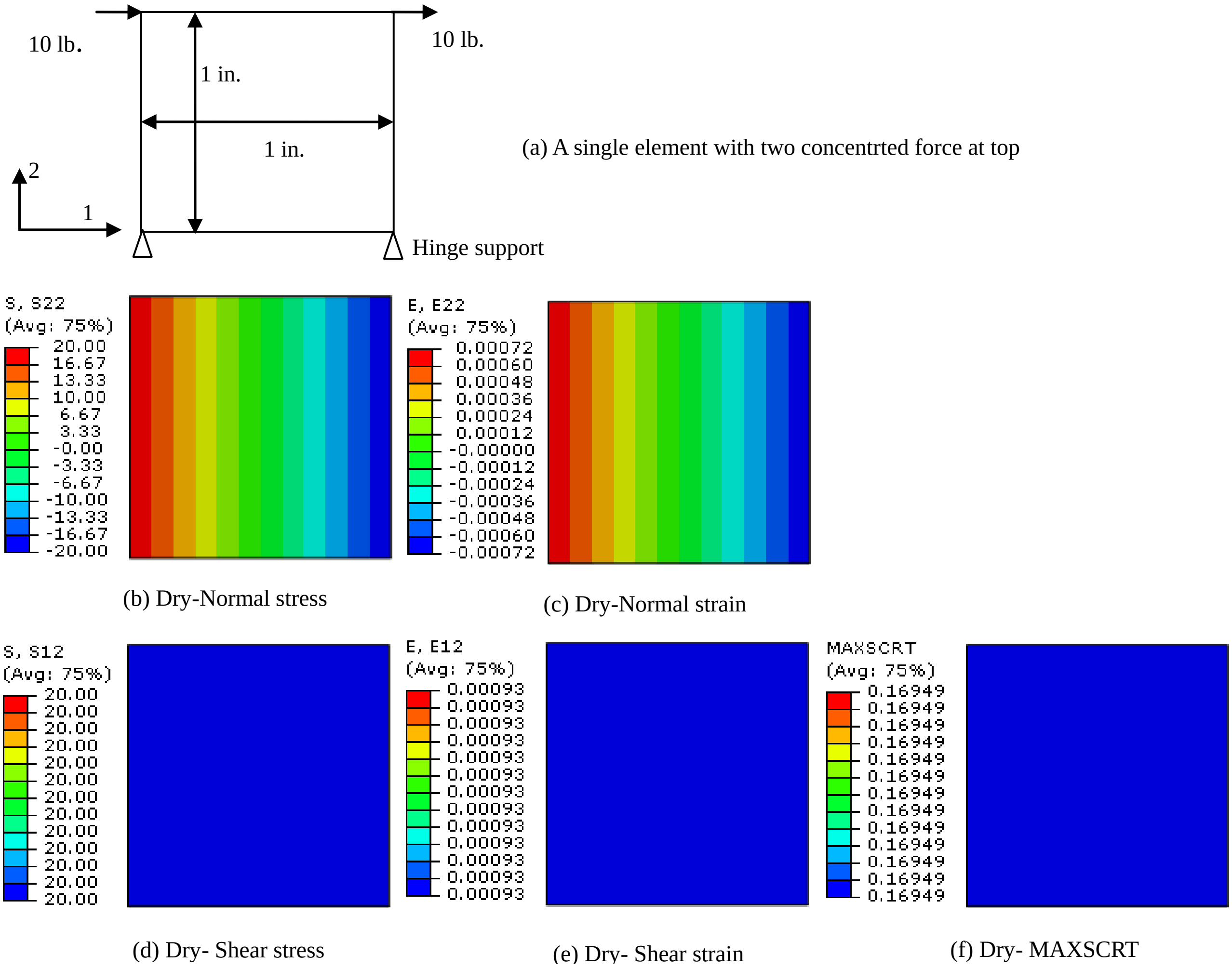


Fig. 3. Maximum Stress Criteria (MAXSCRT) Damage Model Verification under Dry Condition.

than dry conditions. It should be noted that the material is not damaged yet until the MAXSCRT value is 1.0. MAXSCRT value less than 1.0 means, the material is not damaged yet but will damaged if a higher magnitude load is applied. So, according to the previous example, wet samples will damage faster than dry samples if load increases from 10 lb (44.5 N) to 100 lb (444.8 N). It should be noted that both stiffness and strength are important parameters for computing MAXSCRT value. If stiffness is high, stress is high but when strength is high, the MAXSCRT value might have lower magnitudes.

Results and Discussions

Damage inside the matrix and the mastic materials are determined by calculating MAXSCRT value following Eqs. (1) and (3). Damage inside the matrix material is considered cohesive damage and damage inside the mastic material is considered as adhesive damage.

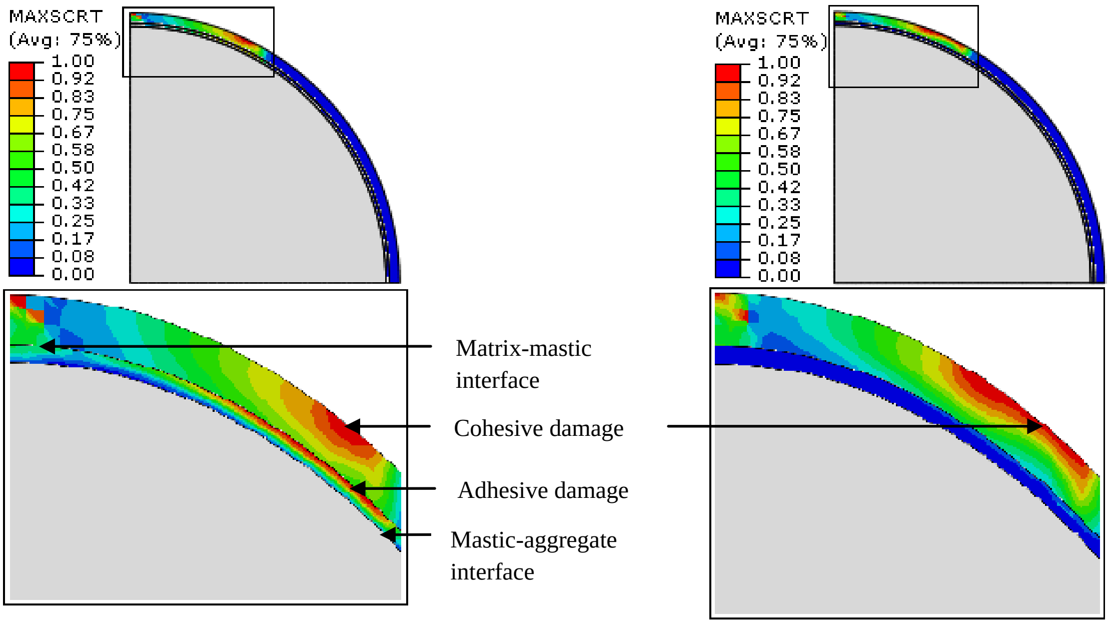
Damage Contour Under Static Deformation

A 1.45 mm. (0.057 in.) uniformly distributed static deformation is applied on the surface of the matrix to evaluate cohesive and adhesive damages in AC. Fig. 4(a) shows the MAXSCRT contour under dry conditions and Fig. 4(b) shows it under wet conditions. The contour image ranges from blue (gray on gray scale) to red (black on gray scale), where red (dark on gray scale) means damaged location and MAXSCRT value equal to 1.0. The other color shows the undamaged locations with a different MAXSCRT value less than 1.0. According to Fig. 4(a), matrix material is exposed to cohesive damage at end of the deformation zone under dry conditions. Also, under the matrix-mastic interface there are some adhesive damaged locations under dry conditions. On the other hand, cohesive damage inside the matrix material is higher under wet conditions than that of dry conditions. More locations of matrix material are exposed to damage under wet conditions than dry conditions. But no adhesive damage was observed inside the mastic material.

MAXSCRT value is higher under wet condition than dry condition as it is shown in the FEM model verification section. Wet conditions show higher cohesive damages than dry condition inside matrix material since the stiffness is higher under dry conditions than wet conditions. But this phenomenon is not true for adhesive damage inside mastic material even though stiffness under dry conditions is higher than under wet conditions. The interface between the matrix and mastic material might causing the differences. For this analysis the matrix-mastic and mastic-aggregate contact is assigned as default cohesive contact available in ABAQUS.

Damage Contour Under Dynamic Deformation

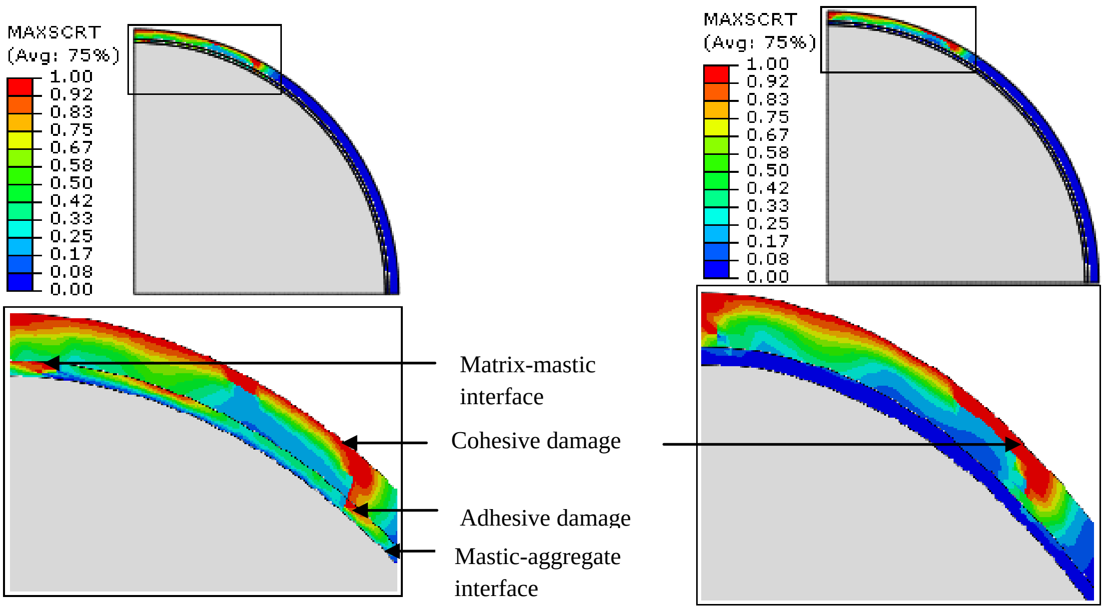
A 1.45 mm (0.057 in.) peak amplitude and one cycle dynamic deformation is applied on the surface of matrix to evaluate cohesive and adhesive damages in AC. Fig. 5(a) shows the MAXSCRT contour under dry conditions and Fig. 5(b) shows it under wet conditions. According to Fig. 5(a), both cohesive and adhesive damage is observed under dry conditions but only cohesive damage is observed under wet conditions, but cohesive damage is higher under wet conditions than under dry conditions. By comparing Figs. 4 and 5, it can be seen that dynamic deformation causes significantly higher damage than static deformation under both dry and wet conditions. For static deformation, the deformation increases gradually with time up to 0.10 sec, on the other hand for dynamic deformation, the deformation increases in 0.05 sec and then decreases in 0.05 sec. Same magnitude deformation applied in



(a) Dry- static deformaiton

(b) Wet- static deformation

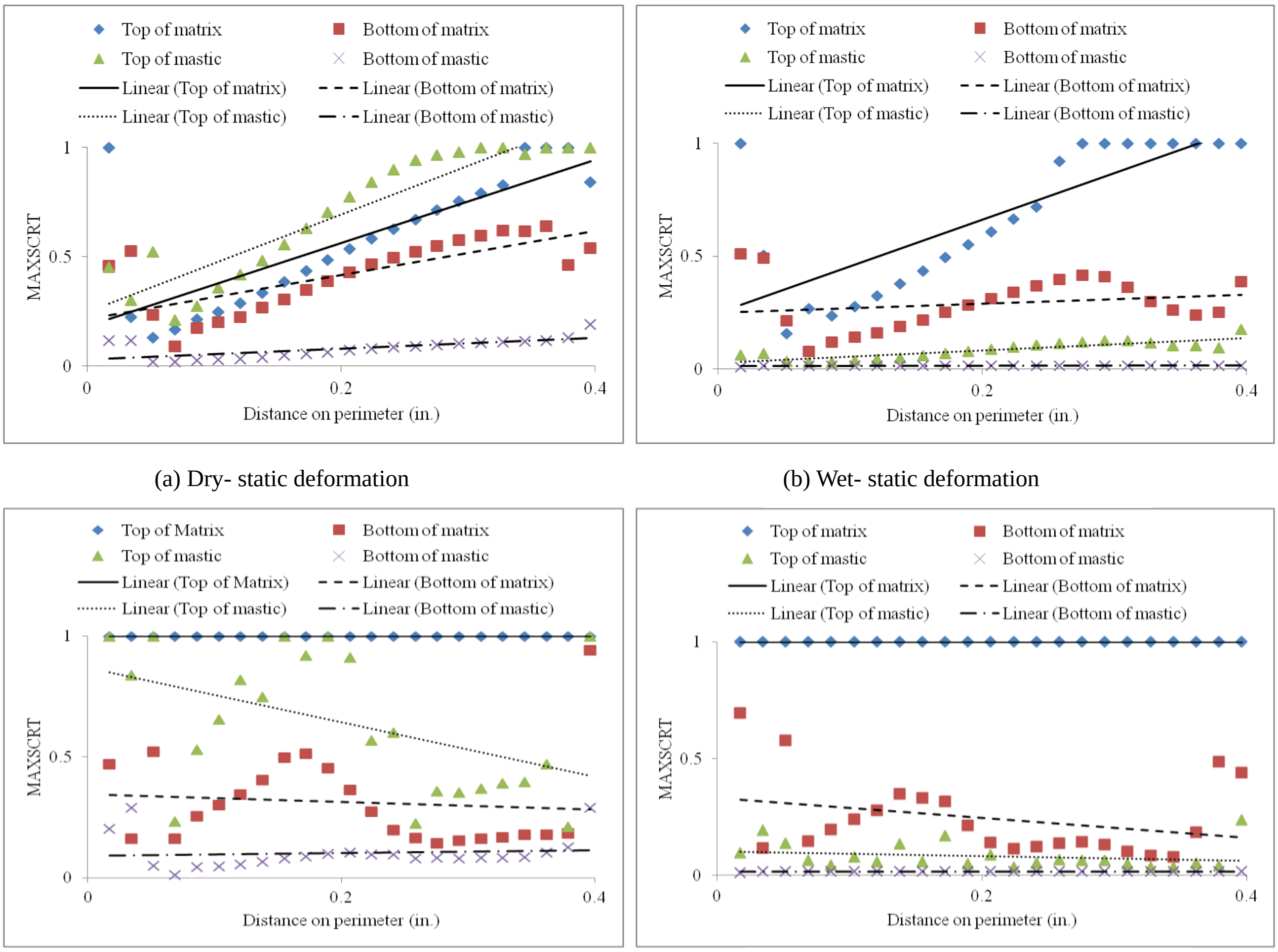
Fig. 4. Maximum Stress Criteria (MAXSCRT) for 1.45 mm. (0.057 in.) Static Deformation Under Dry and Wet Conditions.



(a) Dry- dynamic deformation

(b) Wet- dynamic deformation

Fig. 5. Maximum Stress Criteria (MAXSCRT) for 1.45 mm. (0.057 in.) Dynamic Deformation under Dry and Wet Conditions.



(a) Dry- static deformation

(b) Wet- static deformation

(c) Dry- dynamic deformation

(d) Wet- dynamic deformation

Fig. 6. Maximum Stress Criteria (MAXSCRT) Variations for Static and Dynamic Deformations under Dry and Wet Conditions.

shorter time could increase damage for one cycle dynamic simulation than static simulation.

Damage Initiation, Progression, and Variation

According to Fig. 4(a), damage initiates at the end of the applied deformation zone. Cohesive damage mostly progresses on the surface of the matrix according to Fig. 4(a) and 4(b). Cohesive damage progresses into matrix material and towards mastic material while deformation application changes from static to dynamic according to Fig. 5(a) and Fig. 5(b). An element is damaged when its stress carrying capacity is reached to a certain limit. When an element is damaged, it cannot carry any deformation. Stress carrying capacity of the adjacent undamaged element increases and eventually damaged when it reached to its ultimate strength. This process continues until the end of the analysis period. Stiff material such as matrix carries more deformation than less stiff material such as mastic.

Damage variations inside the matrix and mastic materials are difficult to identify by only observing contour plots. For this reason, MAXSCRT values are plotted in Fig. 6 for the top surface of matrix, bottom of matrix (i.e. top of matrix-mastic interface), top of mastic (i.e. bottom of matrix-mastic interface), and bottom of mastic (i.e. top of mastic-aggregate interface) elements. The x-axis is the distance on perimeter measuring from the top-left corner for each layer (i.e. top and bottom surface or interfaces). The x-axis is scale up to 10.16 mm (0.40 in.) since the deformation is applied on the top surface of matrix up to 10.16 mm (0.40 in.) Fig. 6(a) and 6(b) are plotted for static deformation under dry and wet conditions respectively and Fig. 6(c) and 6(d) are plotted for dynamic deformation under dry and wet conditions respectively. Both MAXSCRT value at each element and the linear trend lines are plotted. Trend lines are plotted since it is observed that MAXSCRT value does not follow any pattern and varies from element to element and mostly near interface location. Also, the elements near the left support show variations; the left side boundary conditions might influence MAXSCRT computation for these elements

It is observed that both adhesive and cohesive MAXSCRT value increases while distance increases for static deformation. Yet both cohesive and adhesive MAXSCRT decrease while distance increases for dynamic deformation, except cohesive damage at the top surface of matrix for the specified distance. MAXSCRT value is 1.0 for all elements at the top surface. The significance of Fig. 6(a) is, adhesive MAXSCRT value in mastic is higher than cohesive

MAXSCRT value in matrix material. Comparing Fig. 6(a) and (b), it can be mention that, cohesive damage is higher in matrix material under wet condition but adhesive damage is higher under dry condition for static deformation. Comparing Fig. 6(c) and (d), it can be said that, indeed cohesive damage is occurring in matrix material under both dry and wet conditions for dynamic deformation.

Conclusions

FEM model is used to determine cohesive and adhesive damages in AC. FEM model is prepared considering an aggregate particle coated with mastic material and surrounded by matrix material. Maximum stress criteria is used to identify damage in matrix and mastic material. Damage in matrix material is considered as cohesive damage and damage in mastic material is considered as adhesive damage. FEM models are analyzed under static and one cycle of dynamic deformations under dry and wet conditions. The results are summarized below,

- Cohesive damage initiates at the surface of matrix and then propagates towards mastic material and initiate adhesive damage.
- Adhesive damage is more comparing cohesive damage under dry conditions but cohesive damage is significantly higher under wet conditions for static deformation.
- Cohesive damage occurs under both dry and wet conditions for dynamic deformation. Adhesive damage is higher under dry condition comparing to wet condition for dynamic deformation.

Both stiffness and strength of matrix and mastic material are important to compute cohesive and adhesive damages. More laboratory tests should be performed on mastic material especially under wet conditions since the shear strength is showing higher comparing to the dry strength and that influences the simulation results.

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