Asphalt Research Consortium
## Fatigue

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Work Elements  Hypothesis

1c. Aging
- Incorporate aging effect

1a. Cohesive and Adhesive Properties
1b. Viscoelastic Properties
1d. Healing

Material Property Inputs

3c. Continuum fatigue model
3b. Micromechanics model

Compare results / provide parameters

2a. Binder test and effect of composition
2b. Mastic / FAM testing protocol
2c. Mixture testing protocol
2d. Microstructure characterization (CT)
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F1c. Aging

**Objectives:**

1. To assess material and microstructure characteristics of mixtures as affected by oxidative aging
2. Effect of aging on fundamental material properties
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F1c. Aging

**Research Approach:**

- Literature review and detailed work plan
- Develop a transport model for oxidative aging in pavements based on
  - binder oxidation kinetics,
  - model for calculating temperature as a function of time and depth
  - model for oxygen transport and diffusion in binder

- Determine effect of oxidative aging on material properties such as viscoelastic properties, fracture resistance, and healing (Later Start)
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F1c. Aging

Relevance to Area Goal and Other Work Elements:

1. Transport model can be used to determine the extent of oxidative aging as a function of:
   - climate
   - depth below the asphalt pavement surface
   - microstructure characteristics of the mixture
   - properties of the binder (activation energies, oxygen reaction order values, oxygen diffusion coefficient)

2. Change in material properties as a function of aging is an essential input for long term modeling of pavement performance using continuum models or long term modeling of mixture performance using micromechanics model
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Work Elements

Hypothesis

1c. Aging
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1a. Cohesive and Adhesive Properties

1b. Viscoelastic Properties

1d. Healing

Properties

Material Property Inputs

3c. Continuum fatigue model

3b. Micromechanics model

Models

Compare results / provide parameters

Test Methods

2a. Binder test and effect of composition

2b. Mastic / FAM testing protocol

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F1a. Cohesive and Adhesive Properties

**Objective:**
To provide a fundamental material property for micromechanical modeling of asphalt mixture

**Research Approach:**
- Refine existing protocols to determine thermodynamic work of adhesion / cohesion
- Evaluate and select models and test methods to quantify mechanical work of adhesion / cohesion
- Develop relationship between thermodynamic work of adhesion / cohesion to mechanical work of adhesion / cohesion for binders and mastics
F1a. Cohesive and Adhesive Properties

Relevance to Area Goal and Other Work Elements:

1. Work of cohesion / adhesion is an important material property input for:
   • micromechanical models to evaluate mixture performance
   • analytical models that can be used as a part of the continuum model to evaluate pavement performance

2. This work element will produce recommendations for the most suitable protocol (thermodynamic or mechanical) to obtain these important material properties
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Work Elements

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1b. Viscoelastic Properties

1d. Healing

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Material Property Inputs

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F1b. Viscoelastic Properties

Objective:

To determine linear and non-linear viscoelastic properties of asphalt materials

Research Approach:

• Evaluate and select suitable model to capture non-linear effect of viscoelasticity in cyclic loading, eg. Schapery's non-linear model
• Develop a test protocol to determine the parameters required for the model
• Conduct cyclic load tests under different stress / strain amplitudes and apply the model to separate viscoelastic properties and damage from the test response
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F1b. Viscoelastic Properties

**Relevance to Area Goal and Other Work Elements:**

1. Non-linearity and damage have similar manifestation in a cyclic load test. Developing a model to capture non-linear viscoelastic response of the material in a cyclic load test is important to differentiate between the two

   ![Graph](image)

   - **Non-linear**
   - **Linear**

   Phase angle from cyclic load test is an averaged representation of linear & non-linear response, therefore it cannot be extended from one stress/strain amplitude to another

2. This analytical model can be combined with crack propagation criterion for use in a continuum model to predict fatigue cracking performance of a pavement subjected to different magnitudes and rates of loading.
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Work Elements  ←  Hypothesis

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Test Methods
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F1d. Healing

**Objective:**

1. To determine a time dependent material property that can be used to characterize the net healing between crack surfaces, and

2. To determine the relationship between these properties, healing, and endurance limit

**Research Approach:**

- Evaluate mechanisms of healing and select materials that best represent these mechanisms

- Review and select test methods that measure properties related to healing or a time dependent material property that quantifies healing

- Express healing in a form that can be readily accommodated in existing analytical models for crack growth

- Measure endurance limit for different materials and evaluate its relationship to healing parameter
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F1d. Healing

**Relevance to Area Goal and Other Work Elements:**

Healing is an integral part of the fatigue process. Determining a parameter that represents the time dependent healing characteristics of different asphalt materials is an essential input for any micromechanical or continuum model.
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Work Elements ➔ Hypothesis

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F3b. Micromechanical Models

**Objective:**

To develop a micromechanical model that will unify material and mixture properties to predict the performance of a mixture

**Research Approach:**

- Two approaches of DEM and FEM will be considered
- Two different length scales will be considered in each model:
  - Use of binder and filler properties to predict performance of mastic
  - Use of mastic and aggregate properties to predict performance of the mixture
- The models will be validated/calibrated using a combination of mechanical tests and NDT such as X-Ray CT
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F3b. Micromechanical Models

**Relevance to Area Goal and Other Work Elements:**

Micromechanical models are important to evaluate and predict the material performance.

In most cases, once the material properties for a suite of different materials is available, it would require only computational work to determine material proportions and binder – filler – aggregate combinations that yield the most optimal performance for a given service condition.
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Test Methods
F3c. Continuum Fatigue Model

**Objective:**

To develop a continuum fatigue model that will unify material and mixture properties to predict the pavement performance in terms of fatigue and plastic or permanent deformation.

**Research Approach:**

- Two approaches, a viscoelastic-viscoplastic model and the...
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F3c. Continuum Fatigue Model

Relevance to Area Goal and Other Work Elements:
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Work Elements ↔ Hypothesis

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F2. Test Methods

**Objective:**

1. To qualify and select materials during the mixture design process
2. To obtain material property inputs required for micromechanical and continuum modeling
3. To validate and/or calibrate micromechanical models

**Research Approach:**

Test methods and multi scale modeling will be conducted at different length scales:

- materials
- mastic
- fine aggregate matrix
- mixture