Asphalt Research Consortium

Overview of Modeling Approaches

Models ETG – Irvine, Feb. 2009

Background

- ARC modeling components are integrated to provide a coordinated mechanics approach to predict pavement performance
- Each model component contributes to the ability to reliably predict damage
- Some models (e.g., materials characterization) are
  - intended to extract or “filter” material properties as input to continuum models while some are
  - Intended to simply characterize (or even rank order) material behavior
- Other models intended to focus on the prediction of performance at a macro-scale

Background

- **Models**
  - **Performance Prediction Models**

    Purpose: Use material properties to predict performance of an asphalt material or pavement structure

    - **Micromechanics Models**
    - **Continuum Models**
  - **Material Characterization Models**

    Purpose: Capture the impact of a process on material properties and specific responses typically in order to rank and select materials (can serve as a model input)

Micromechanics Models

- Definition – Analyze a composite or heterogeneous material using properties of individual phases that constitute the material
- Goal – Predict the responses of the composite
- Benefit – Determine behavior without resorting to testing of composite

Micromechanics Models

- Purpose in ARC approach

  Serve as computational models that:

  - develop basic understanding of nucleation and propagation of micro cracks and their effect on overall stiffness,
  - link to continuum models, which predict pavement performance, and
  - form the basis for specification tool: i.e., estimate the binder's resistance to fatigue cracking when used with various aggregate types and gradations

Background

Models

Performance Prediction Models

Purpose: Use material properties to predict performance of an asphalt material or pavement structure

Material Characterization Models

Purpose: Capture the impact of a process on material properties and specific responses typically in order to rank and select materials (can serve as a model input)

Micromechanics Models

Continuum Models

Continuum Models

- Definition – Analyze kinematics and mechanical behavior of materials modeled as a continuum. Assumes that the substance of the body is distributed uniformly
- Goal – Represent material behavior with a constitutive relationship
- Benefit – Can be implemented in computational systems, i.e., finite element computer models

Continuum Models

- Purpose in ARC

  Develop three-dimensional visco-elasto-plastic continuum damage models and implement into finite element method to predict permanent deformation, fatigue cracking and moisture damage. More specifically these models will be used to:

  - predict performance of asphalt concrete and asphalt pavement structure and

  - design and analyze successful mixtures and pavements

Background

Models

Performance Prediction Models

Purpose: Use various material properties together with test data to predict performance of an asphalt material or pavement structure

Micromechanics Models

Continuum Models

Material Characterization Models

Purpose: Capture the impact of a process on material properties and specific responses typically in order to rank and select materials (can serve as a model input)

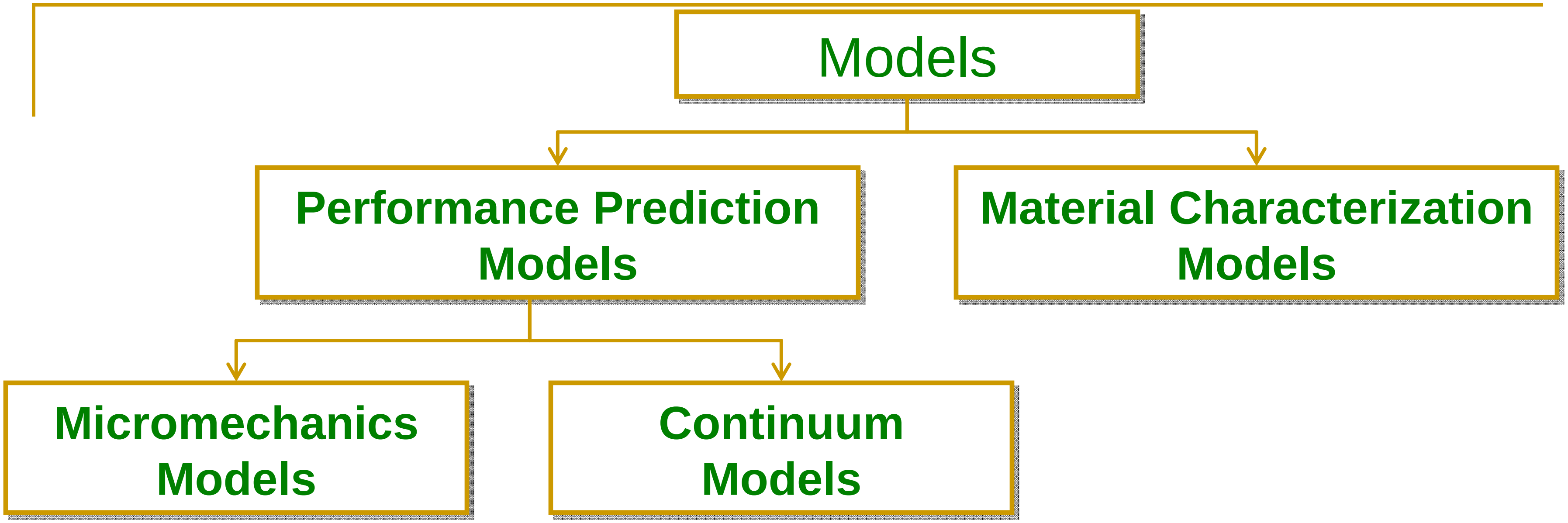
Material Characterization Models

- Purpose

  Capture the impact of a process or processes that alter the material properties and consequently the engineering response of the material or composite

- Examples of Models

  - oxygen diffusion through the matrix of the asphalt mixture *(aging)*,
  - rate of asphalt binder oxidation *(aging)*,
  - moisture diffusion through the binder, mastic or mixture at different length scales *(moisture damage)*,
  - rate of crack wetting and/or intrinsic healing of asphalt binders *(healing)*, and
  - mechanical response of the asphalt mixture based on the response of its individual components and vice-versa *(engineered materials)*



The following are some of the generic questions based on the modeling efforts in ARC (from the view point of researchers and stake holders):

1. How do these models relate to each other?
2. What are the goals of each type of model?
3. What are some examples of these goals?
4. What work is being done on these models and where?

1. How do these models relate to each other? (1/2)

Micromechanics	Continuum	Material Characterization

- Models are **NOT necessarily designed to mesh together** to form a single comprehensive model – nevertheless the 3 approaches are linked and support each other

- Based on current technology, a pragmatic approach is to focus on deliverables that
  - (i) benefit stake holders in the near future,
  - (ii) improve fundamental understanding of damage mechanisms, and
  - (iii) create foundation for future modeling efforts

1. How do these models relate to each other? (2/2)

Micromechanics	Continuum	Material Characterization

Three approaches **GUIDE** each other in several different ways such as:

- Material models provide constitutive relationships that may be used with the micro-mechanics models

- Tests developed as a result of material characterization models may provide input for micromechanics models

- Micromechanics and material models highlight factors and properties that contribute to damage

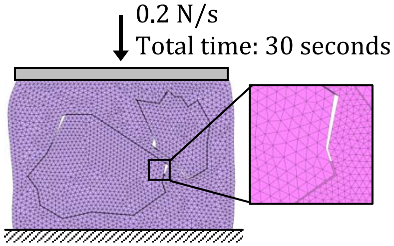
- Micromechanics and material models highlight factors and properties that ***do not*** contribute to damage;

- Continuum models can then focus on the most critical parameters

2. What are the goals for each type of model?

Micromechanics	Continuum	Material Characterization
- Model evolution of damage within the mixture - Provide means for virtual experiments (e.g., parametric relationship(s) between material and mixture properties and damage evolution)	- Predict pavement damage based material properties	- Relate role of material properties to different forms of distress - Provide basis for specification tests to screen materials (mixture design) - Identify test methods to determine useful material properties

3. What are some examples of these goals?

Micromechanics	Continuum	Material Characterization
- A computational FEM model for crack growth incorporating the effect of moisture  - A computational lattice model to simulate damage as a screening tool during the mixture design process	- A continuum model to predict pavement performance that accommodates aging, moisture damage, aggregate surface properties etc.	- Material models and tests for healing and aging, measurement of diffusion of moisture in asphalt binders $R = \int_{\tau=-\infty}^{\tau=t} R_h(t-\tau)\frac{d\phi(\tau, X)}{dt}d\tau$ - Specification type tests to evaluate FAM and rank fatigue cracking resistance of asphalt binders

4. What work is being done on these models and where?

Micromechanics	Continuum	Material Characterization
Micromechanics models are being developed under work elements F.3 and E.1	Continuum models are being developed under work element F.3	Materials characterization, materials characterization models, and test methods are being developed under work elements M.1, M.2, M.4, M.5, F.1, and F.3
Resource allocation for this task is approximately ***5 to 10%*** of the ARC budget	Resource allocation for this task is approximately ***10 to 15%*** of the ARC budget	Resource allocation for this task is approximately ***15 to 20%*** of the ARC budget

Experts in Modeling

- Texas A&M University
  - Bob Lytton
  - Eyad Masad
  - Rashid Abu Al-Rub
  - K. Rajagopal
  - Charles Glover
  - Amy Epps-Martin
- North Carolina State University
  - Richard Kim
  - Murthy Guddati
- University Nebraska - Lincoln
  - Yong Rak Kim
  - David Allen
- University of Texas – Austin
  - Amit Bhasin

Moisture Damage

Category	Specific Work Element	Consortium Partner				
		WRI	TTI	UWM	UNR	AAT
M1. Adhesion	a) Affinity of asphalt to aggregate (test)			X		
	b) Work of adhesion	X	X			
	c) Quantifying moisture using DMA		X			
M2. Cohesion	a) Work of cohesion (surface energy)	X	X			
	b) Impact of moisture diffusion		X			
	c) Thin film rheology and cohesion			X		
M3. Aggregate	a) Aggregate surface characterization		X			
M4. Modeling	a) Development of model		X			
M5. System	a) Moisture damage prediction system	X	X	X	X	X

Fatigue

Category	Specific Work Element	Consortium Partner				
		WRI	TTI	UWM	UNR	AAT
F1. Material / Mixture Properties	a) Cohesive and adhesive properties		X			
	b) Viscoelastic properties		X			
	c) Aging		X			
	d) Healing			X		
F2. Test method Development	a) Binder tests and effect of composition			X		
	b) Mastic testing protocol		X			
	c) Mixture testing protocol		X			
	d) Microstructure characterization (X-Ray CT)		X			
	e) Verification (DSR vs. mixture fatigue)		X	X		
F3. Modeling	a) Asphalt microstructure model	X	X	X		
	b) Micromechanics model		X			
	c) Unified continuum fatigue model		X			
	d) Calibration and validation		X	X	X	

Engineered Materials

Category	Specific Work Element	Consortium Partner				
		WRI	TTI	UWM	UNR	AAT
E1. Modeling	a) Analytical and micro-mechanics based models for composite mixture behavior		X			
	b) Damage resistance characterization for binders			X		
	c) Warm mixtures			X	X	
E2. Design Guidance	a) Comparison of modification techniques			X		
	b) Use of high percentage of RAP	X		X	X	X
	c) Critically designed HMA mixtures				X	
	d) Thermal cracking resistant mixes for intermountain states			X	X	
	e) Design of fatigue and rut resistant mixtures					X

Validation

Category	Specific Work Element	Consortium Partner				
		WRI	TTI	UWM	UNR	AAT
V1. Field Validation	a) Monitoring of Warm Mix pavements	X				
	b) Construction and monitoring of additional pavement sections					
V2. Accelerated Pavement Testing	a) Third-Scale Model Mobile Load Simulator		X			
	b) Construct sections at the Pecos RTC		X			
V3. R&D Application	a) Continual Assessment of Specifications			X		X
	b) Validation through MEPDG sites and evaluation of the MEPDG Asphalt Materials Models				X	

Technology Develpoment

Category	Specific Work Element	Consortium Partner				
		WRI	TTI	UWM	UNR	AAT
TD. Technology Developme nt	1) Prioritize and select products for early development					X
	2) Develop early products					
	3) Identify products for mid-term and long-term developments					X
	4) Develop mid-term and long-term products					X

Technology Transfer

Category	Specific Work Element	Consortium Partner				
		WRI	TTI	UWM	UNR	AAT
TT1. Technology Transfer	a) Consortium web site				X	
	b) Communications				X	
	c) Presentations and publications	X	X	X	X	X
	d) Materials database				X	
	e) Research database				X	