

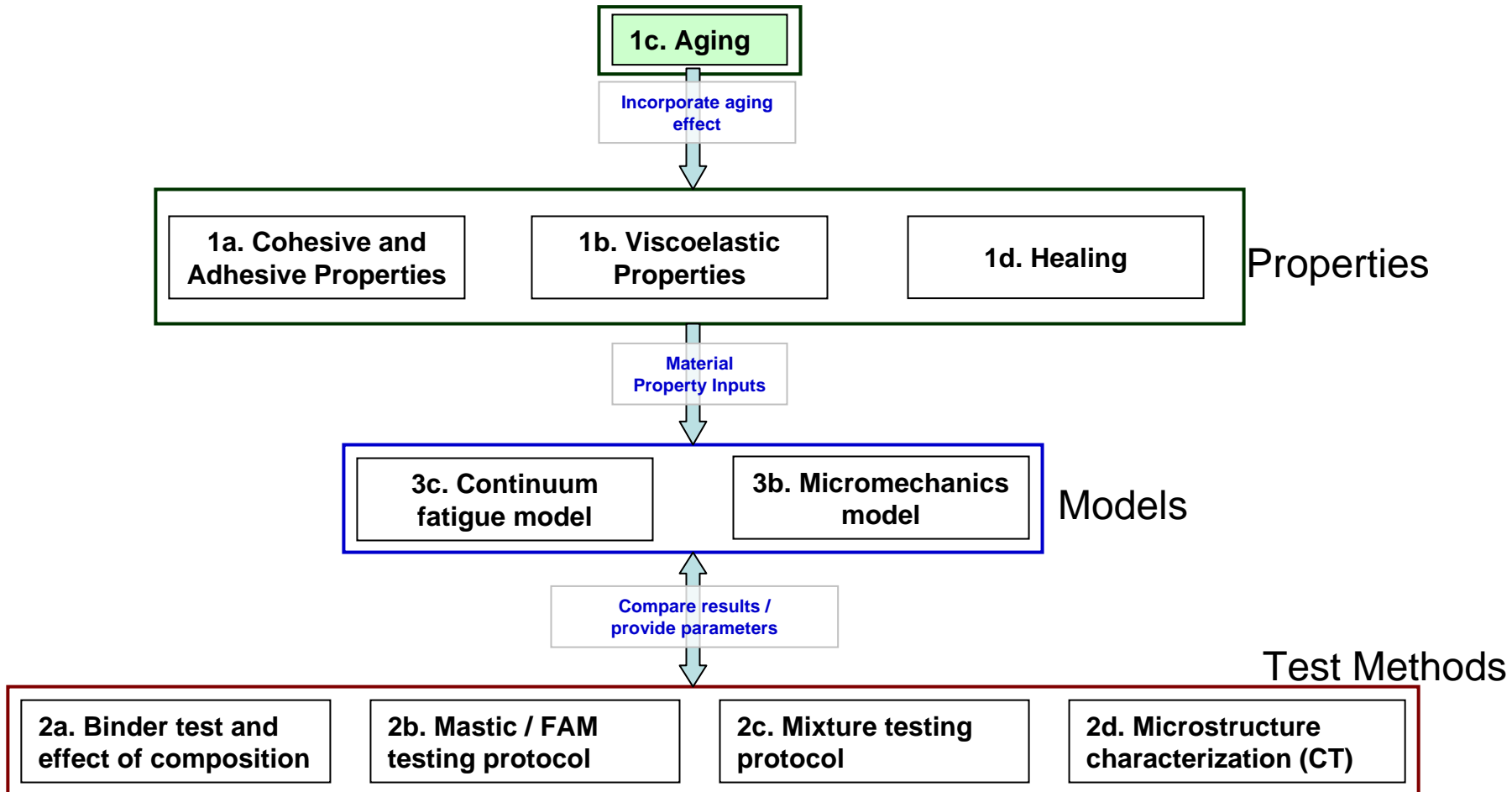
# Asphalt Research Consortium

# 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 Developme nt	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	

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Work Elements  $\longleftrightarrow$  Hypothesis



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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 (activation energies and oxygen reaction order),
  - 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.

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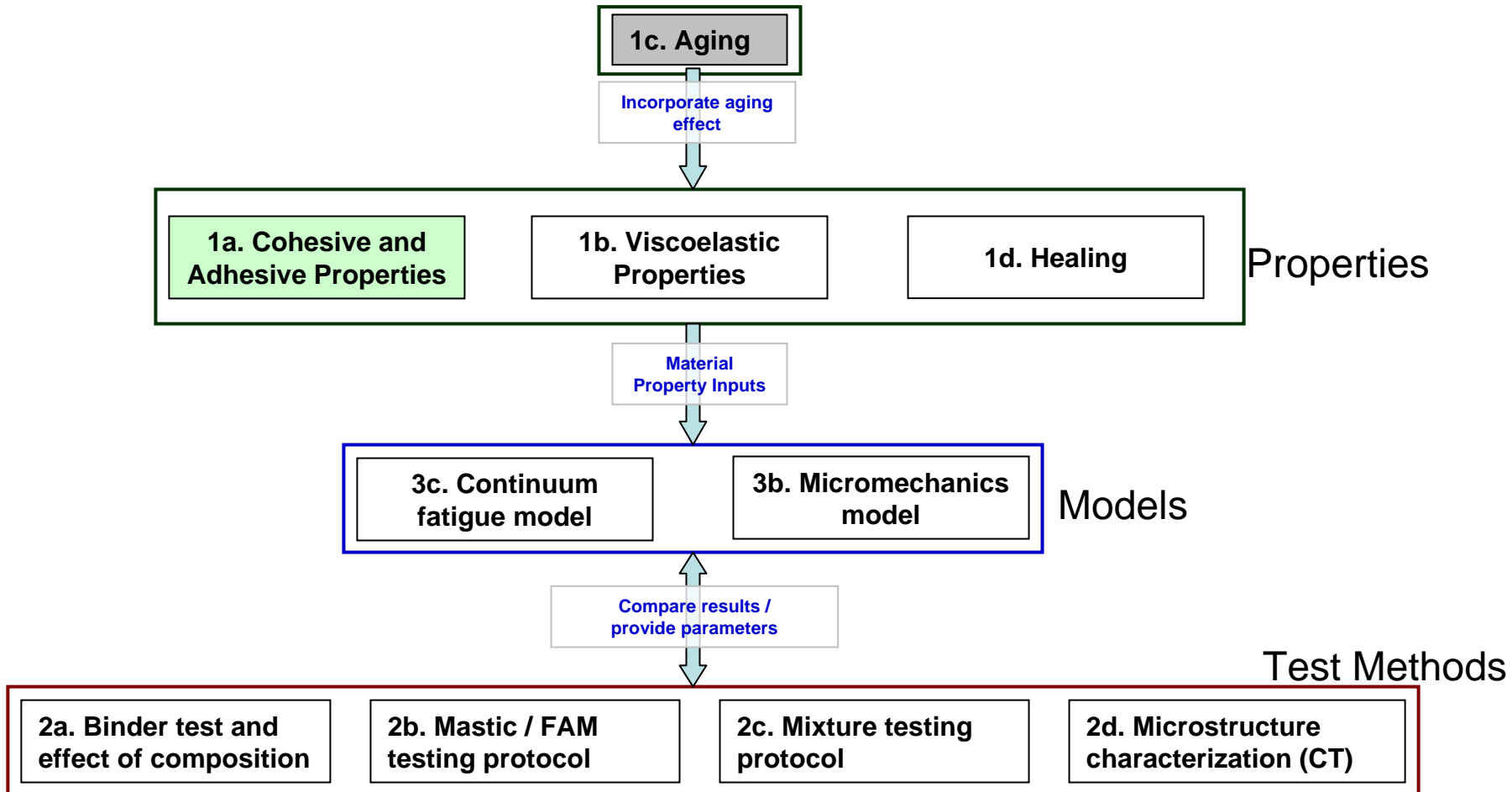
## F1c. Aging

### 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  $\longleftrightarrow$  Hypothesis



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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

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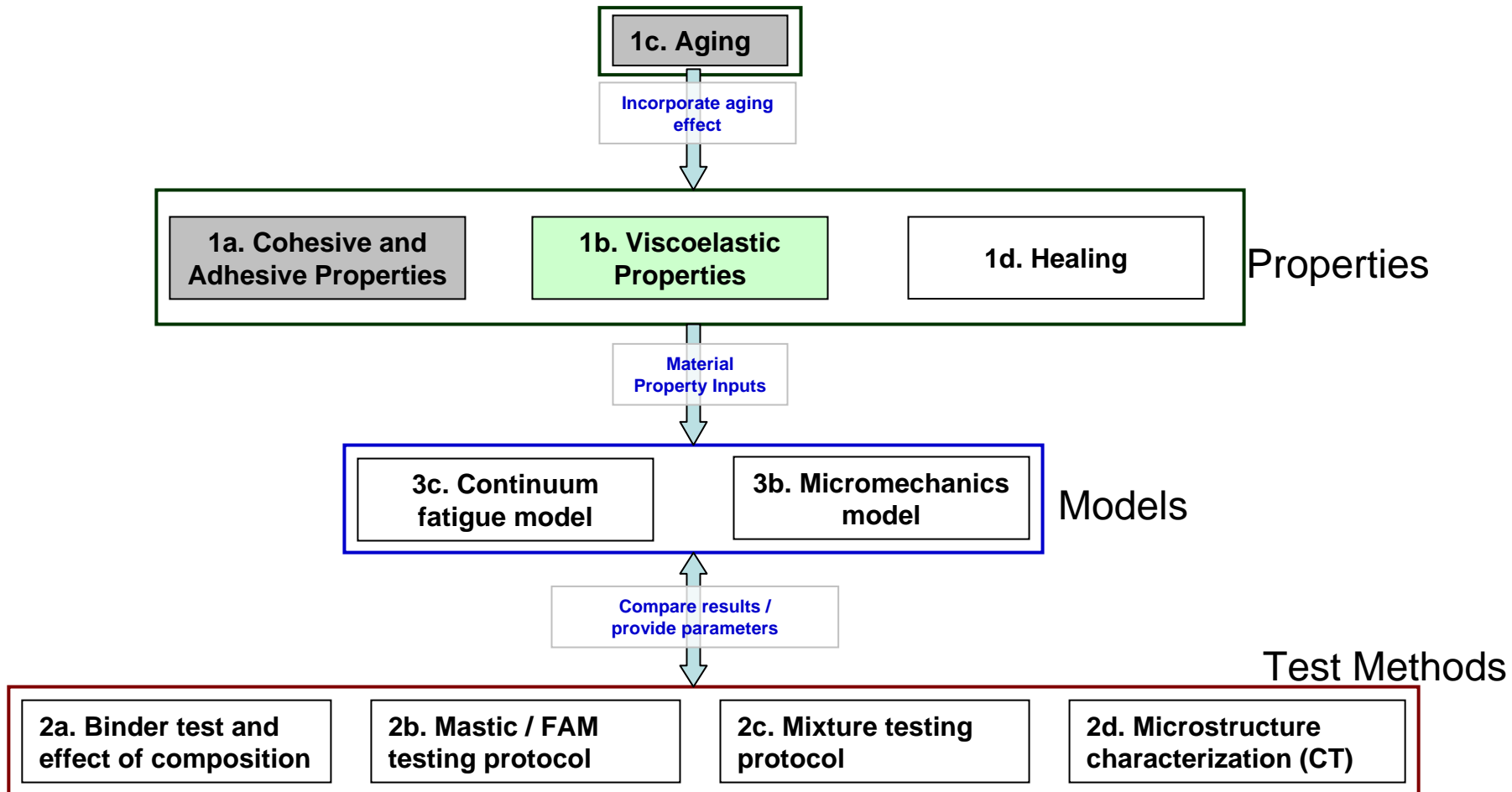
## F1a. Cohesive and Adhesive Properties

### 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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## F1b. Viscoelastic Properties

### **Objective:**

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

### **Research Approach:**

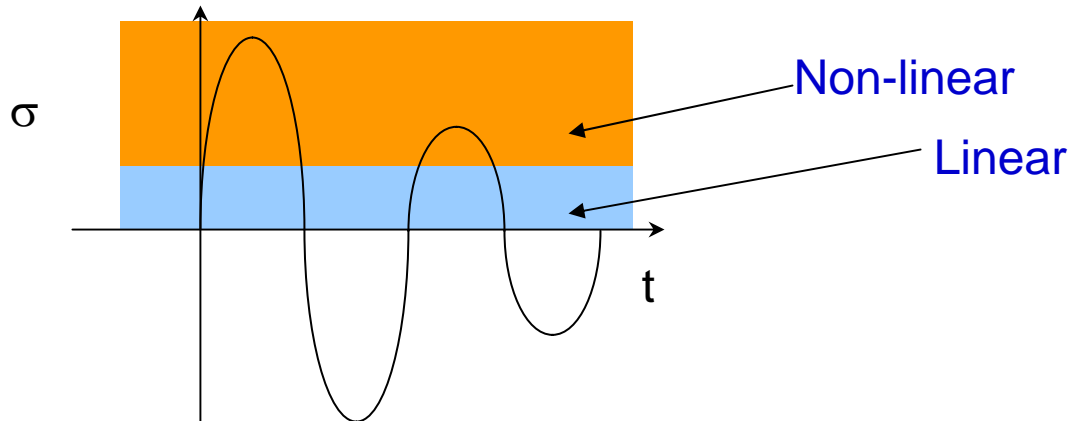
- Evaluate and select suitable model to capture non-linear effect of viscoelasticity in cyclic loading, eg. Schapery's non-linear model
- Develop a test protocol to determine the parameters required for the model
- Conduct cyclic load tests under different stress / strain amplitudes and apply the model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

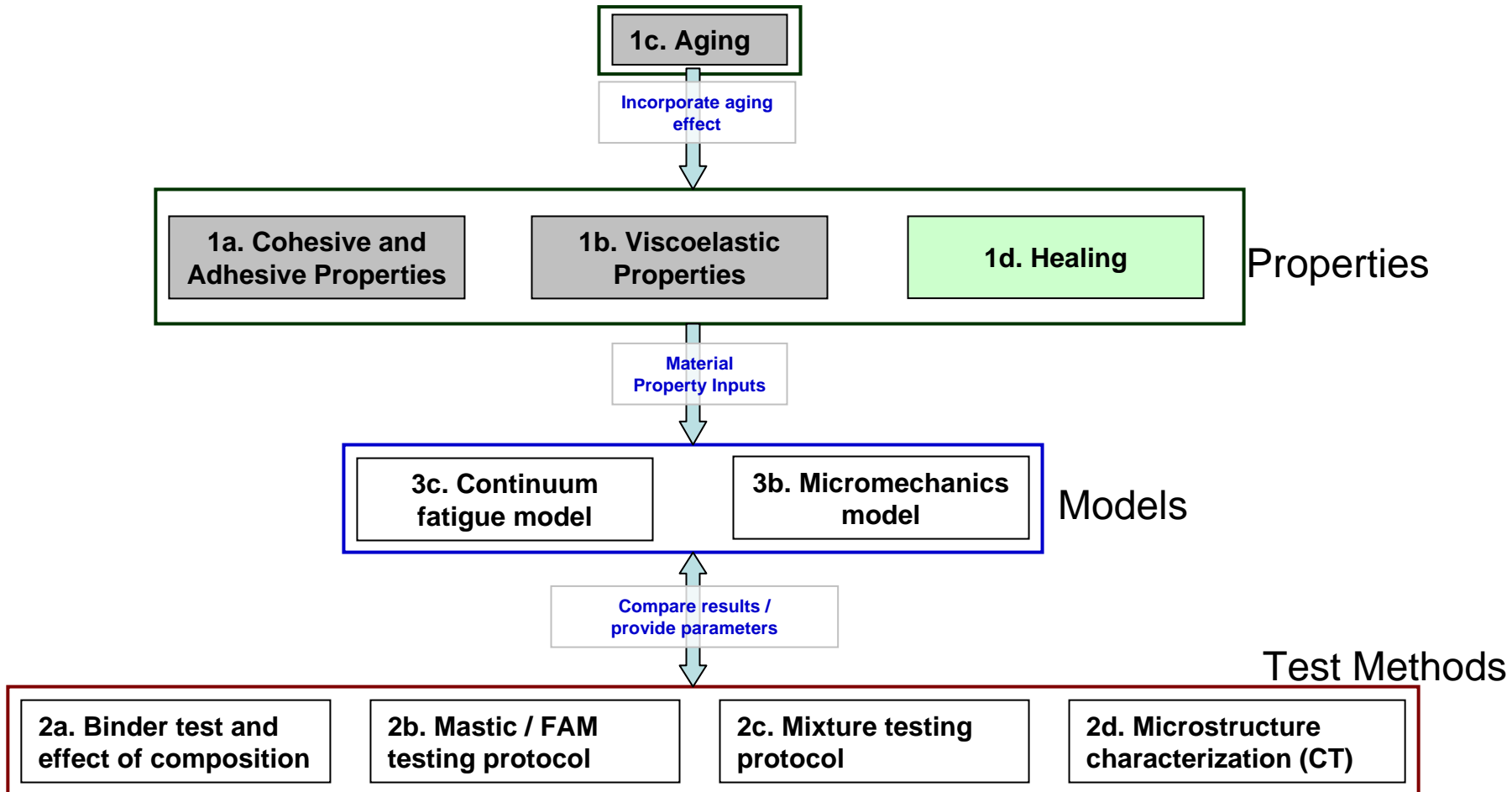


Phase angle from cyclic load test is an averaged representation of linear & non-linear response, therefore it cannot be extended from one stress/strain amplitude to another

2. A systematic approach will be developed to separate the nonlinear viscoelastic response from the viscoplastic response.

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Work Elements  $\longleftrightarrow$  Hypothesis



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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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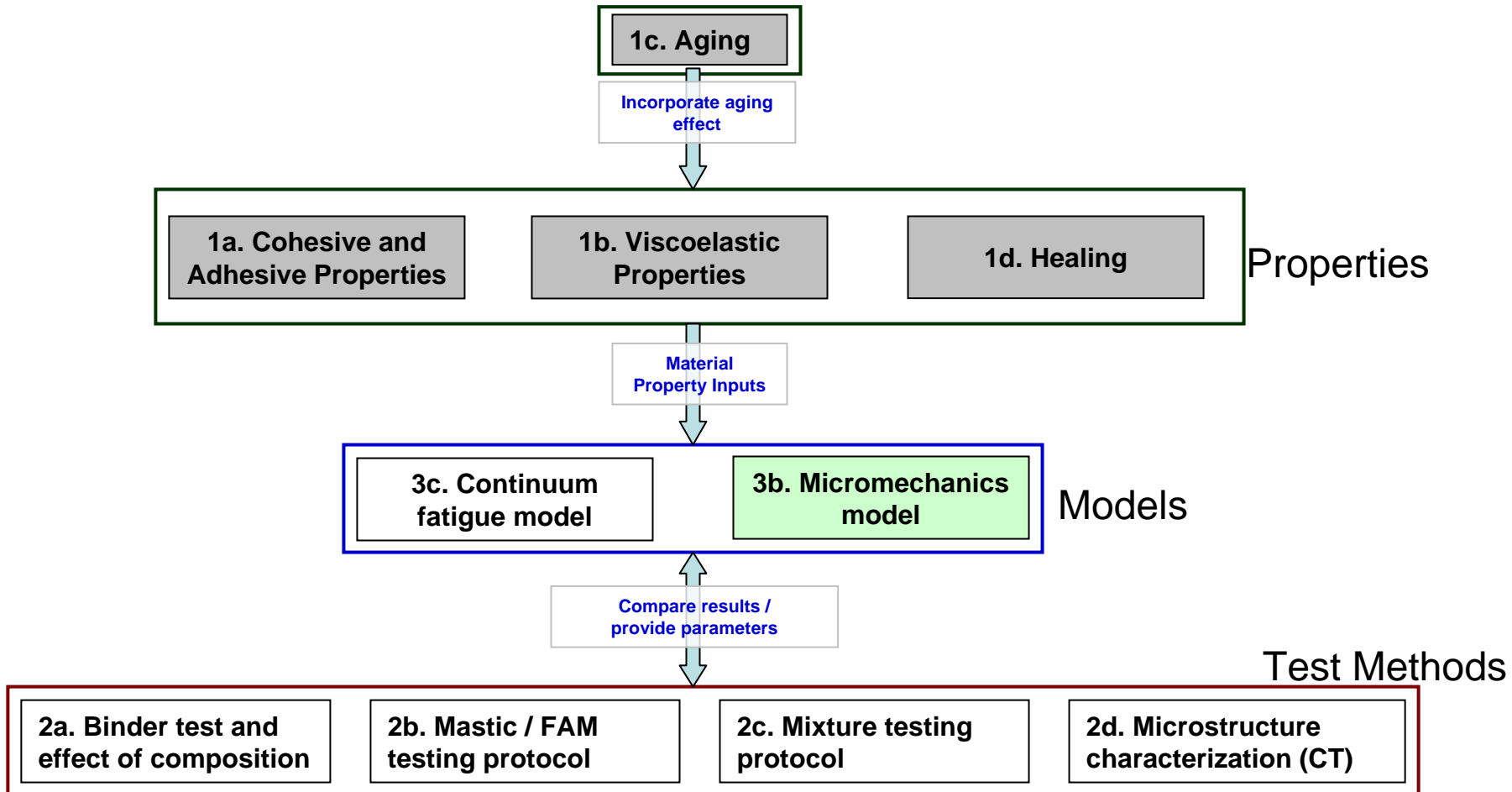
## F1d. Healing

### **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  $\longleftrightarrow$  Hypothesis



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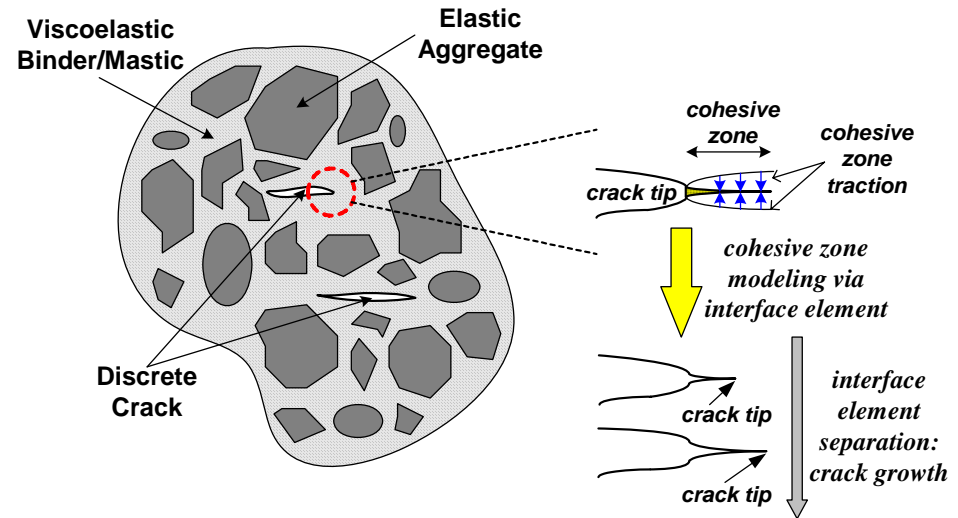
## F3b. Micromechanical Models

### 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

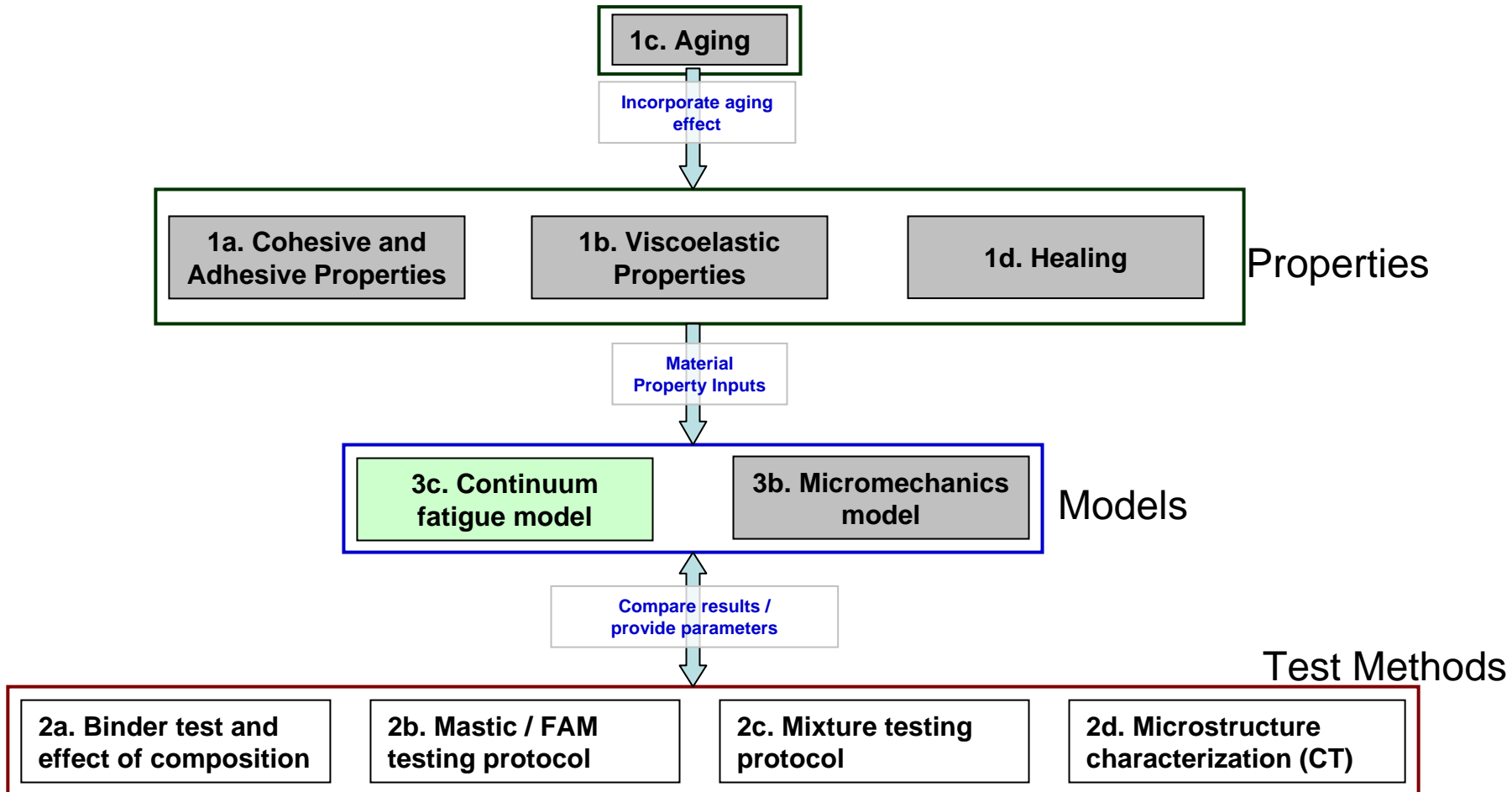
### **Relevance to Area Goal and Other Work Elements:**

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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Work Elements  $\longleftrightarrow$  Hypothesis



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## 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:

$$\Delta R(N) = \left[ (2n + 1)^{n+1} \left( \frac{G_R b}{4 \pi G_1 \Delta G_f} \right)^n N \right]^{\frac{1}{2n+1}}$$

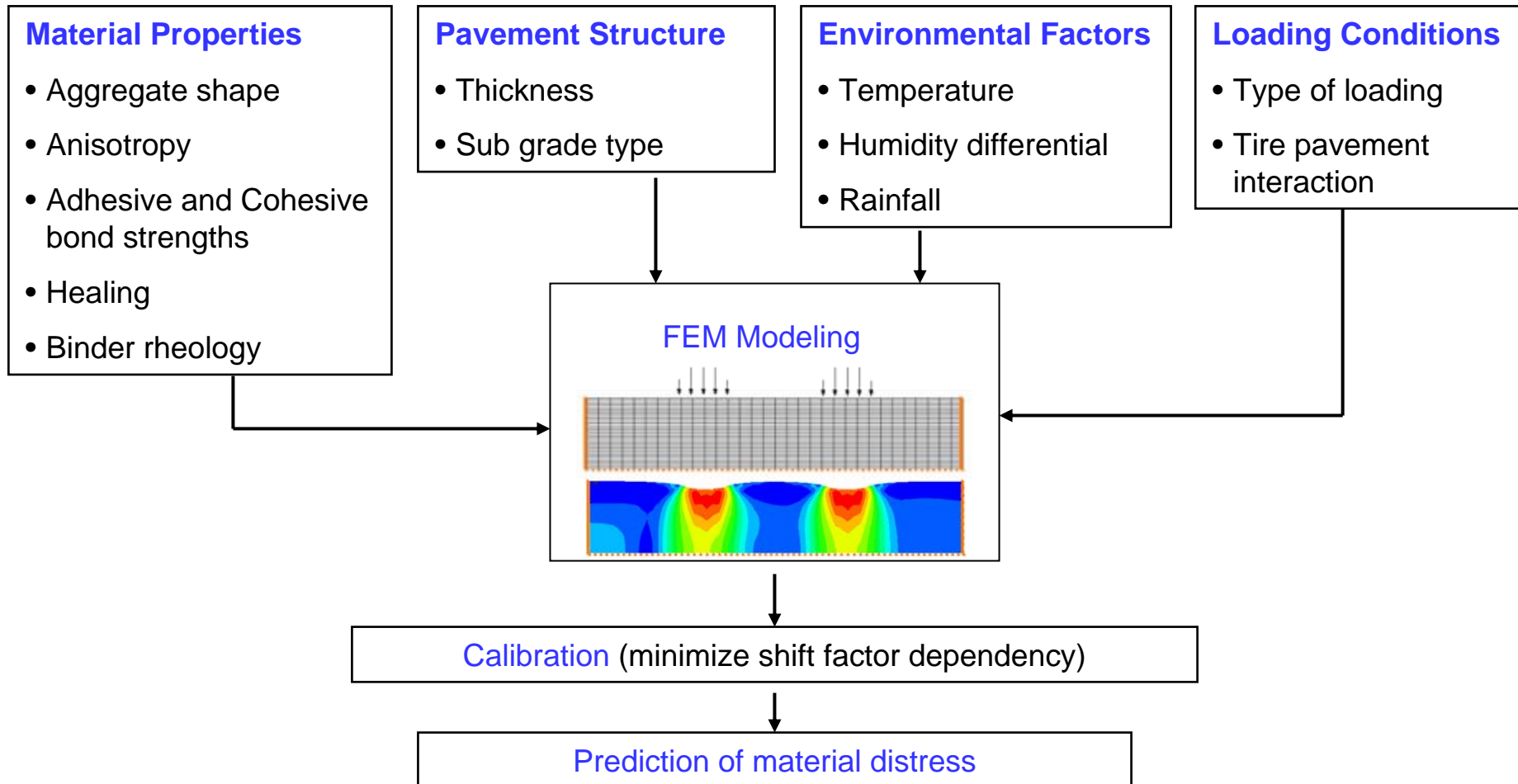
### F3c-1 Analytical Fatigue Model for Mixture Design

A fracture model for predicting the resistance to fatigue loading.

Energy dissipated in fracture, energy dissipated in permanent deformation, physio-chemical properties of mixture (adhesive and cohesive bonds), and viscoelastic properties.

Capable of unifying the results from stress-controlled and strain-controlled tests.

## F3c-2 Unified Continuum Model

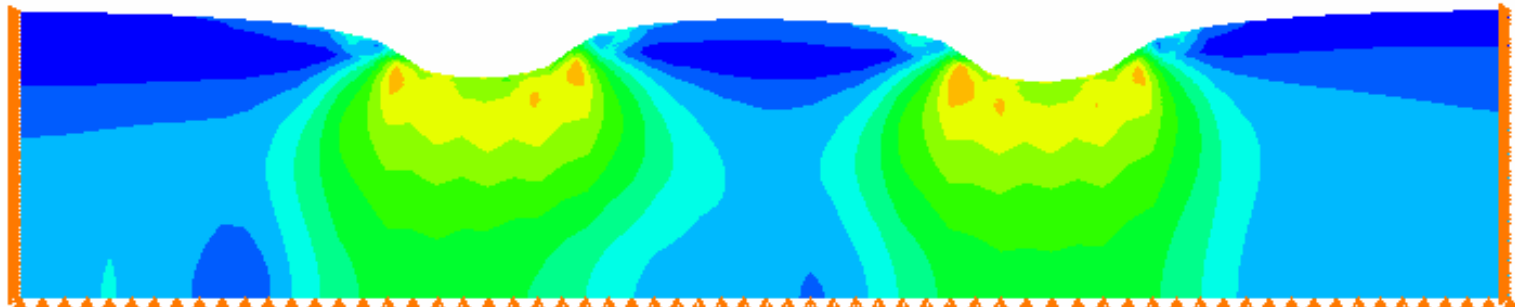


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## F3c-2 Unified Continuum Model

Development of comprehensive viscoelastoplastic continuum damage model that is applicable for wide ranges of temperatures, different loading rates and complex and realistic mechanical and thermal stresses.

- (1) modeling the nonlinear viscoelastic response;
- (2) modeling the effects of microcracks on global constitutive behavior;
- (3) the time-temperature superposition principle;
- (4) strain hardening viscoplastic model for modeling viscoplastic behavior;
- (5) decomposition of nonlinear viscoelastic strain and viscoplastic strain;
- (6) the anisotropic nature of the aggregates structure and damage.

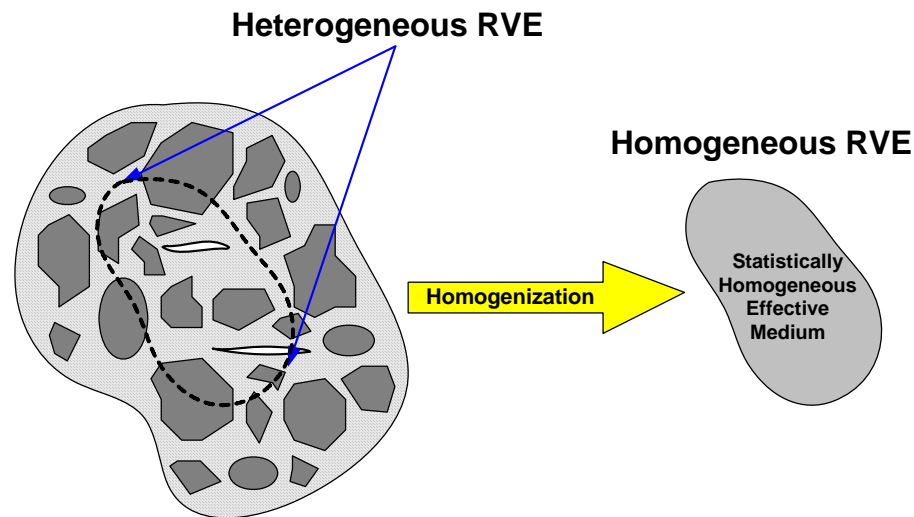


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- 3c-3 Multi-Scale Modeling

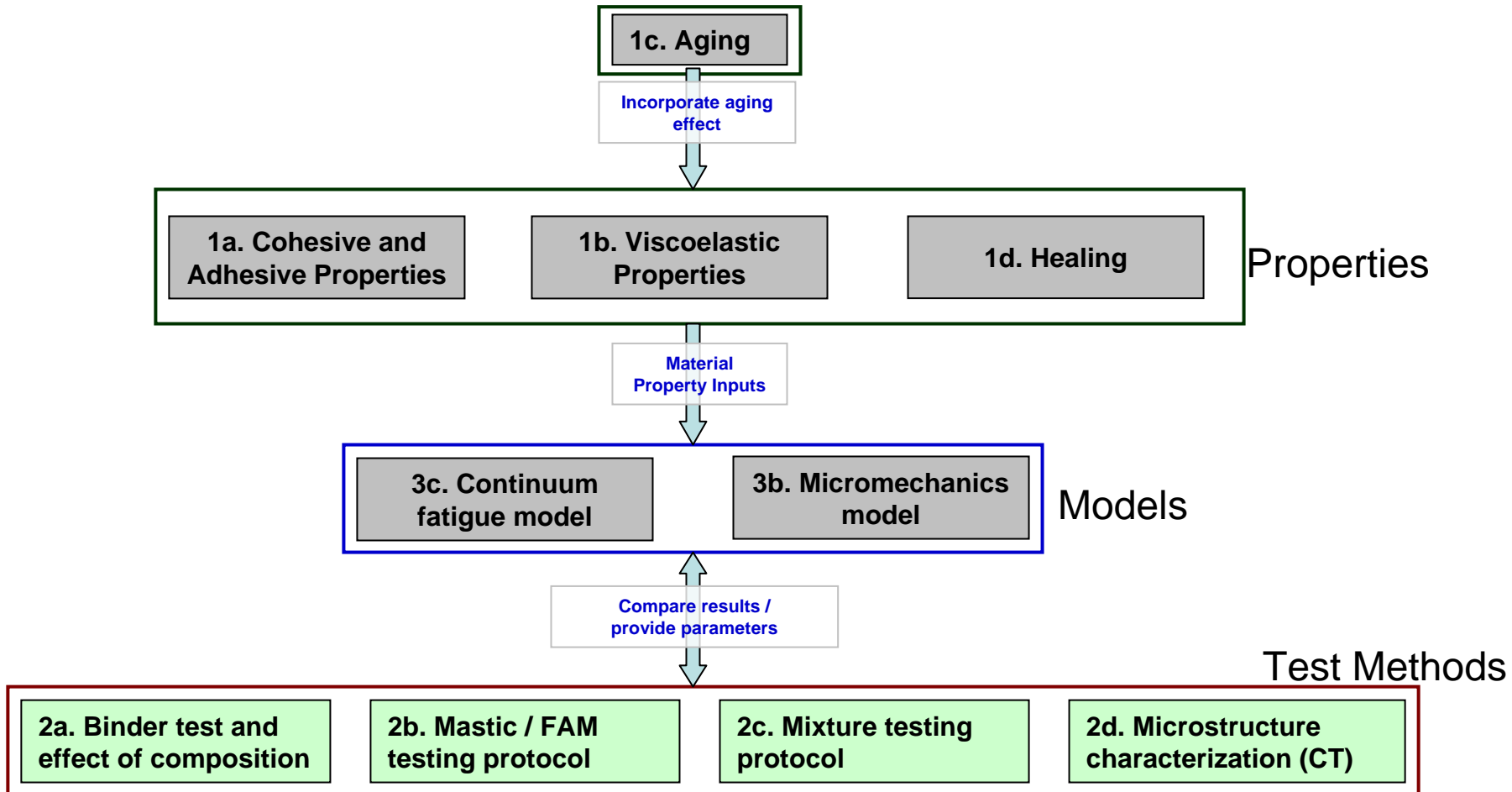
Link the parameters of the continuum model to the fundamental materials properties.

Use the micromechanical models to calculate effective mixture properties that are used as inputs for the continuum model.



# Fatigue

Work Elements  $\longleftrightarrow$  Hypothesis



# Fatigue

## 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