Multi-Continuum Technology for the Failure of Composites

Bart McPheeters

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Introduction

- Multi Continuum Technology (MCT) allows for consideration of micro-mechanical effects in macro-sized FEM models
  - Mechanics of fibers and matrix can be considered individually

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Introduction

- So what?
  - Much more accurate predictions of composite failure
    - Less need for detail models
  - Better knowledge of material failure point
  - Better and lower safety factors
  - Less material
  - Lower cost and weight

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Introduction

- MCT Technology developed by Firehole Technology
  - Firehole's Helius product
  - Implemented in NEi Nastran

MCT

- Why do we need MCT?
- Traditional failure theories have been developed based on smeared lamina properties
  - Fibers and matrix are smeared into one
  - Testing and verification needed to develop and tweak models
  - Called the 'Black Aluminum' approach

MCT

- So?
- Smeared properties have limited usefulness
  - Failure theories treat composite as a whole
  - Analysis output is for composite, not individual components
  - Limits to what it can accomplish

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MCT

- MCT separates the fibers and matrices
  - Different stiffness
  - Different failure properties
    - Fiber failure theory for fibers
    - Polymer failure theory for matrix
  - Different Thermal properties
  - Interaction between the two important

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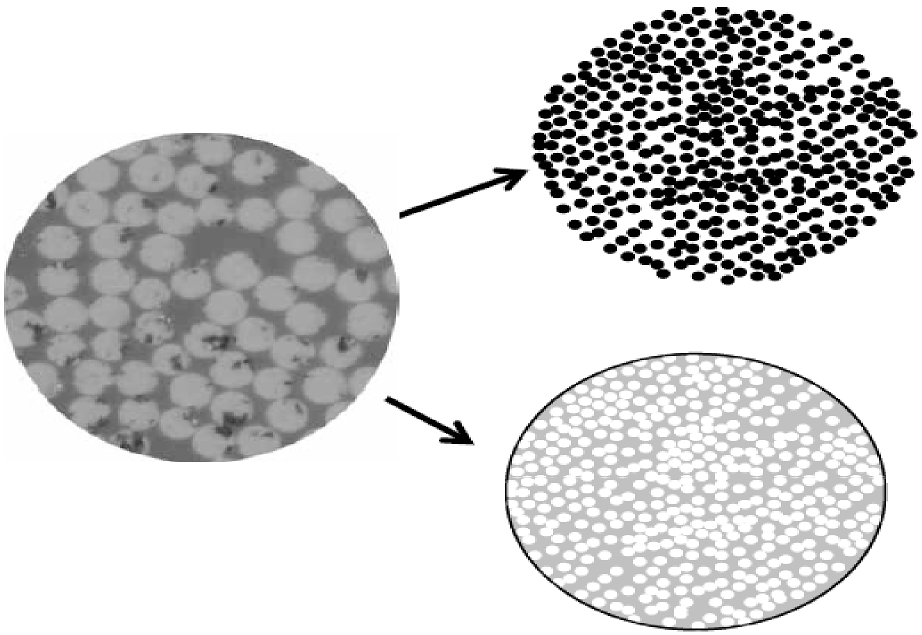
MCT



FEA Outputs:

$\varepsilon_{composite}$, $\sigma_{composite}$

ε_{fiber}, σ_{fiber}

ε_{matrix}, σ_{matrix}

Failure Information:

FI_{Fiber}, FI_{Matrix}

R_{Fiber}, R_{Matrix}

Exact Failure Mode

Better Information = Better Designs

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MCT

- Advantages to this approach
  - Proper failure criteria can be applied to the individual constituents
  - 3D failure theory
    - Off-axis stresses are calculated
  - Interactions can be handled to a degree
  - Can handle unidirectional **and** woven materials

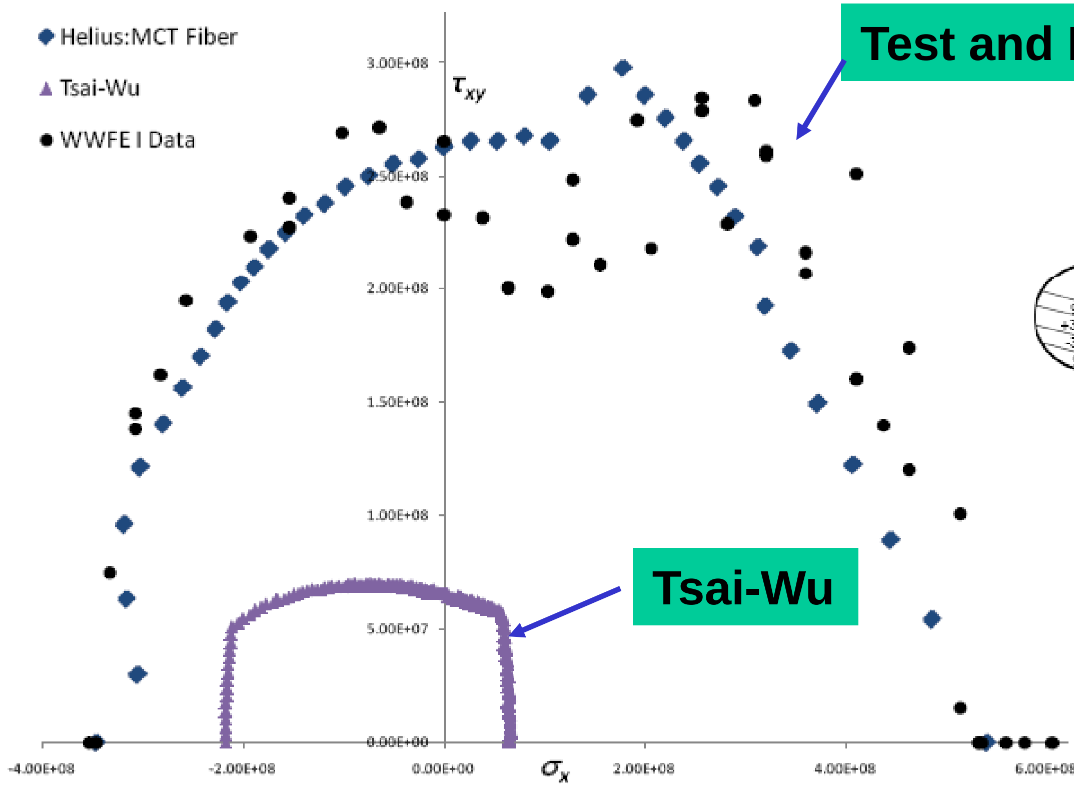
MCT

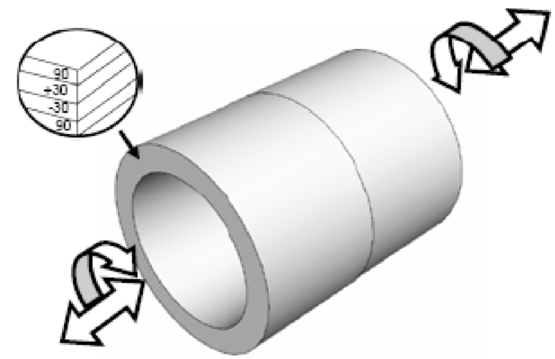
- Hasn't this been done before?
- In a way…
  - – Micro-mechanics are usually applied to small details
    - Accurate capture of interaction
  - – Smeared properties used for large models
    - Less accurate results
  - – **MCT captures the accuracy of the detail, but in a large model**

MCT

- How do we know this works?
  - The MCT approach has been correlated against many tests and actual failures
  - MCT matches WWFE test results better than most traditional failure theories

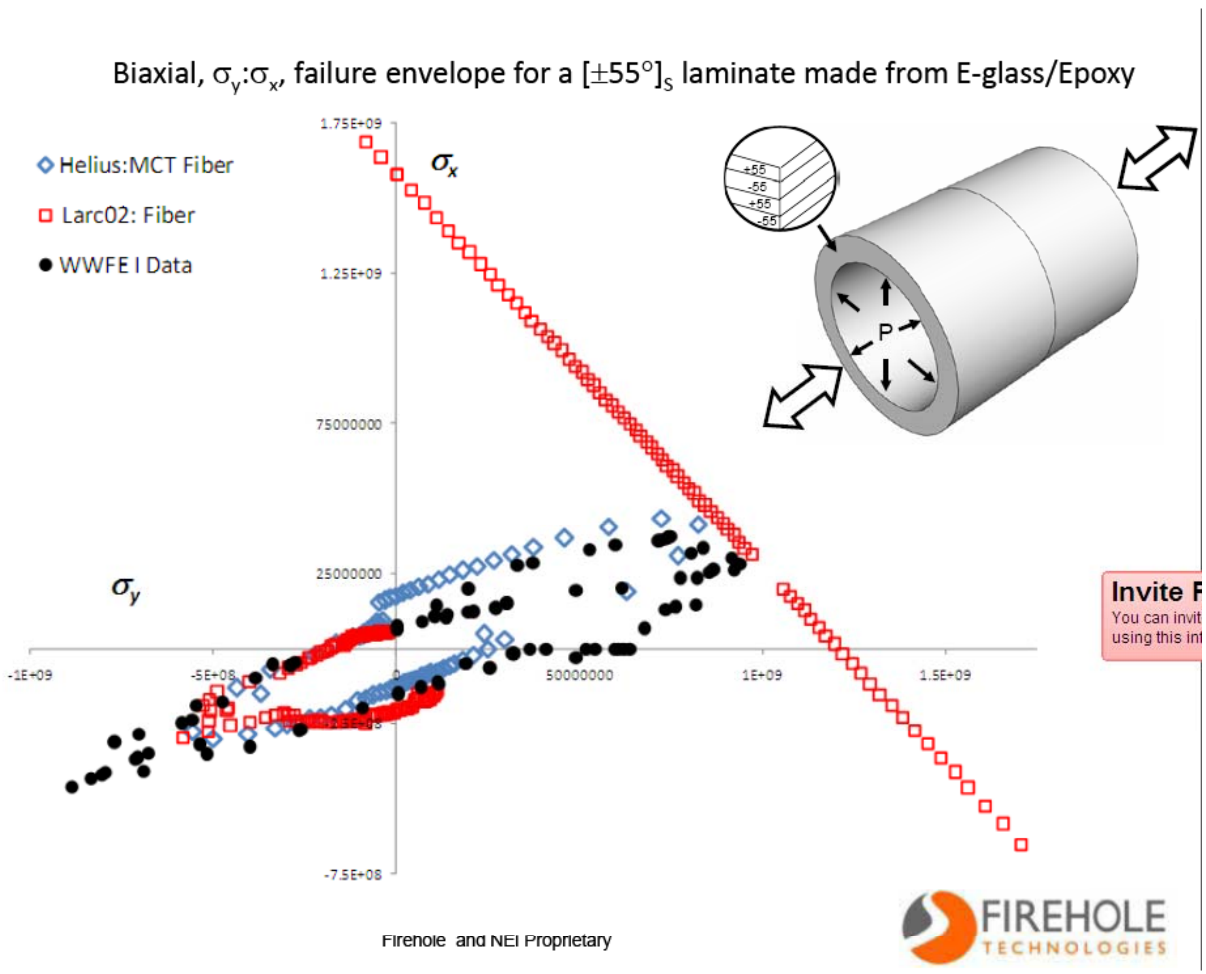
MCT





Biaxial σ_x: τ_{xy} failure envelope for a [90 / 30]$_s$ glass/epoxy lamina

MCT



Biaxial, σy:σx, failure envelope for a [±55°]S laminate made from E-glass/Epoxy
Helius:MCT Fiber
Larc02: Fiber
WWFE I Data
σx
σy
1.75E+09
1.25E+09
75000000
25000000
-7.5E+08
-1E+09
-5E+08
50000000
1E+09
1.5E+09
+55
-55
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TECHNOLOGIES

MCT Mechanics

- How does this all work, then?
  - Properties are input for the constituents
    - Fiber properties
    - Matrix Properties
  - Properties are then calculated/optimized for the composite.

MCT Mechanics

- FEM model is solved with optimized properties, and element strains and stresses are found
- The composite strains and stresses are then decomposed into fiber stresses and fiber strains based in the individual properties and the micro-mechanical models
- Fibers and matrix results can then be handled separately
  - Failure
  - Strength
  - Stiffness

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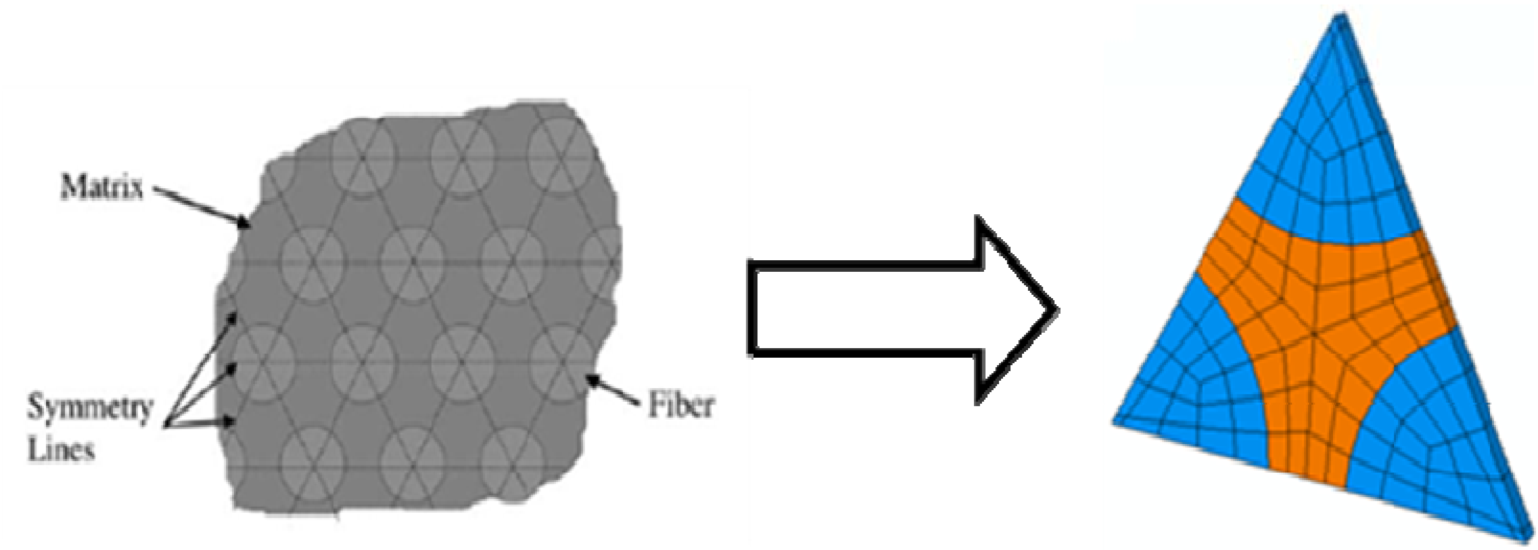
MCT Mechanics

- Ideally, the user inputs material properties for the fibers and matrix
  - Small micromechanical models are constructed and run inside Helius to come up with ‘composite’ properties
  - These ‘optimized’ properties are used for the big FEM model

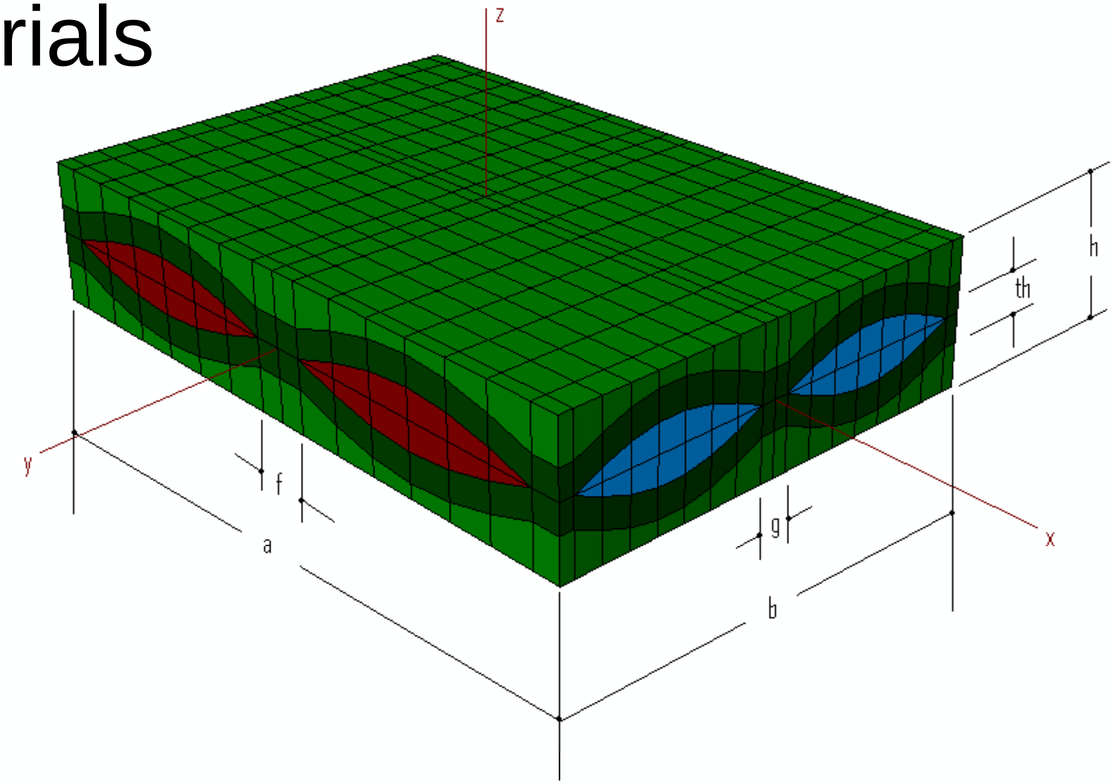
MCT Mechanics

- Micro-mechanics model for Unidirectional materials



MCT Mechanics

- Micro-mechanics model for woven materials



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MCT Mechanics

- The small models are called RVEs "representative volume elements"
- Loads from the model elements are applied to the RVEs
- A detailed 3D picture of the stress state in the individual components can be developed this way
- Reported as fiber and matrix values

Example

- So what does this buy me?
- A simple thermal example…
  – Consider a block of material subject to a change in temperature

Example

- Without any constraints, this is a zero stress event for an isotropic material
- But composites are not isotropic!
  - Fibers and matrix have different CTEs
  - Potentially significant stresses in opposite directions in the fiber and matrix
  - Also out of plane!
  - A traditional failure theory would report the composite stress as zero
    - Because it is treated as a isotropic material

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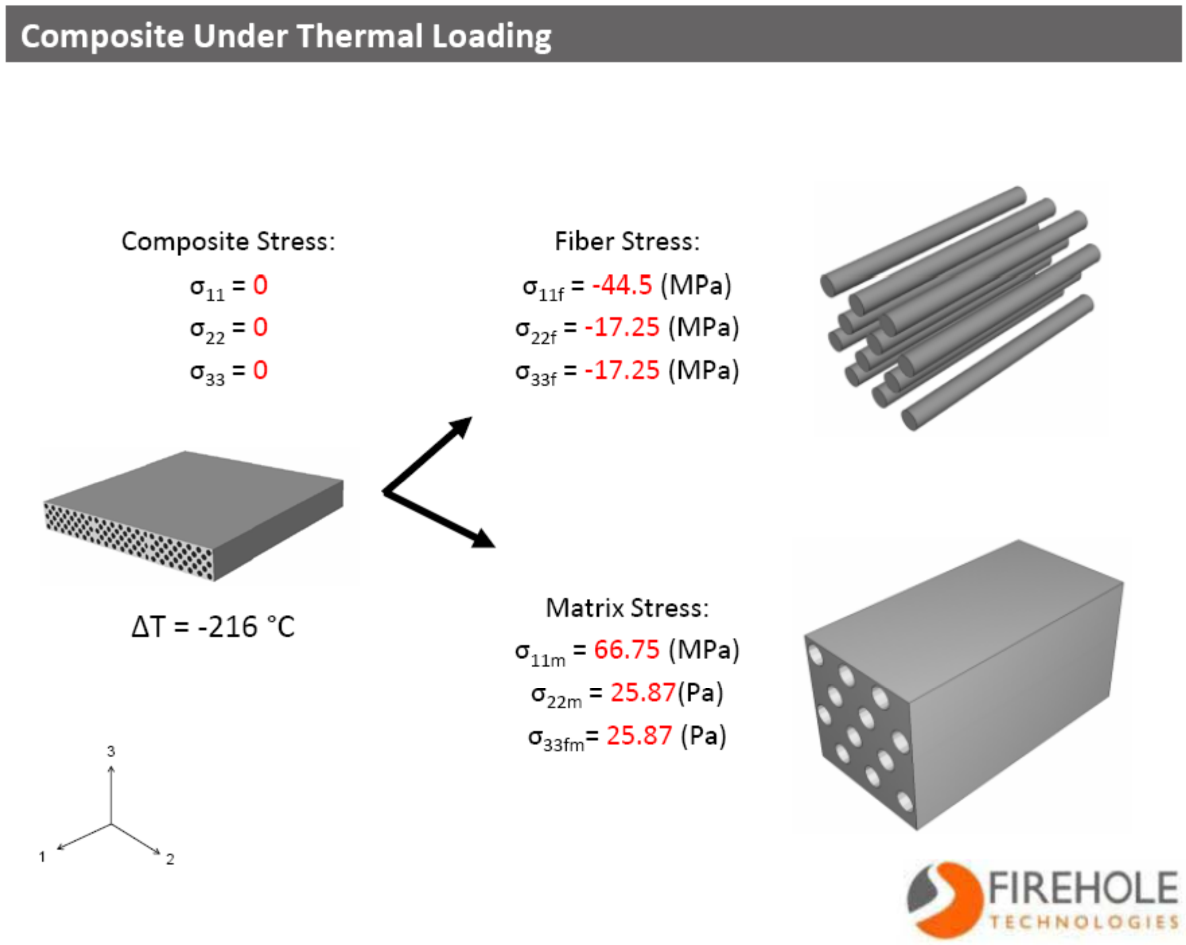
Example



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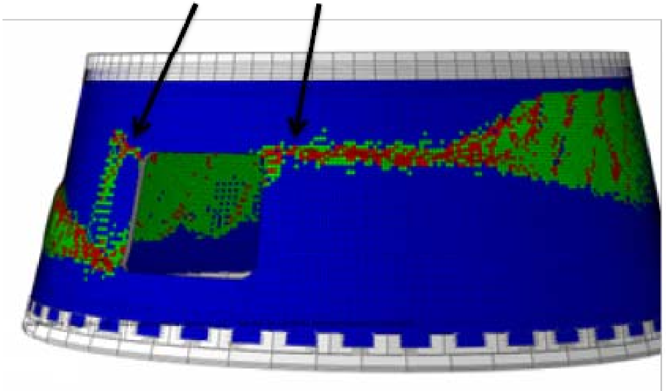
Example

- Structural loading scenarios have similarly unexpected results
  - In-plane loads can generate significant out-of-plane stresses in composites
    - The MCT 3D approach finds these values
  - Delamination may be caused by these loads
    - MCT predicts this better

Example

Results

Helius:MCT Predicted Failure
Red = Fiber Failure
Green = Matrix Failure



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Summary

- MCT is a much better way to predict the actual limits of composites.
- Simple to use – relatively few additional properties needed.
- Better prediction = better design
- Better design = lower material cost, lower weight
- Use MCT today!