HTCMC 5 Abstract

The Effect of Fiber Architecture on Matrix Cracking in SiC/SiC CMC's

Gregory N. Morscher, Ohio Aerospace Institute, Cleveland, OH

Applications incorporating silicon carbide fiber reinforced silicon carbide matrix composites (CMC's) will require a wide range of fiber architectures in order to fabricate complex shapes. The stress-strain response of a given SiC/SiC system for different architectures and orientations will be required in order to design and effectively life-model future components. The mechanism for non-linear stress-strain behavior in CMC's is the formation and propagation of bridged-matrix cracks throughout the composite. A considerable amount of understanding has been achieved for the stress-dependent matrix cracking behavior of SiC fiber reinforced SiC matrix systems containing melt-infiltrated Si. This presentation will outline the effect of 2D and 3D architectures and orientation on stress-dependent matrix-cracking and how this information can be used to model material behavior and serve as the starting point for mechanistic-based life-models.

The Effect of Architecture on Matrix Cracking in SiC/SiC CMC's

Gregory N. Morscher
Ohio Aerospace Institute
NASA Glenn Research Center
Cleveland, OH

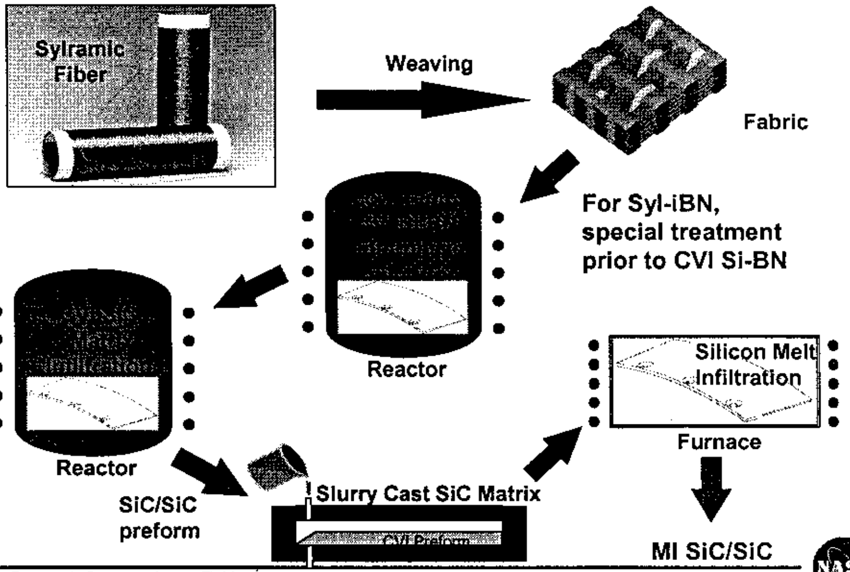
Objective

- To understand the effect of architecture on matrix cracking in CMC's
  - Cause of non-linearity – necessary for modeling σ/ε behavior
  - Access for ingress of oxidation species that lead to strength-degrading embrittlement mechanisms
- To stimulate the use of architecture-based designs for composite applications
  - Architectures offer the potential to enhance matrix cracking stress, interlaminar strength, thermal conductivity, etc...

Outline

- Matrix cracking in 2D Woven systems when stressed in orthogonal directions
  - The standard MI system
  - Ways to improve matrix cracking
- Matrix cracking in some 3D Woven MI systems when stressed in orthogonal directions
- Matrix cracking in 2D woven and braided architectures when stressed in off-axis directions
- Summary and conclusions

Standard Slurry Cast Melt-Infiltrated (MI) 2D Woven Composites



Sylramic Fiber

Weaving

Fabric

For Syl-iBN, special treatment prior to CVI Si-BN

Reactor

Reactor

SiC/SiC preform

Slurry Cast SiC Matrix

CVI Preform

Silicon Melt Infiltration

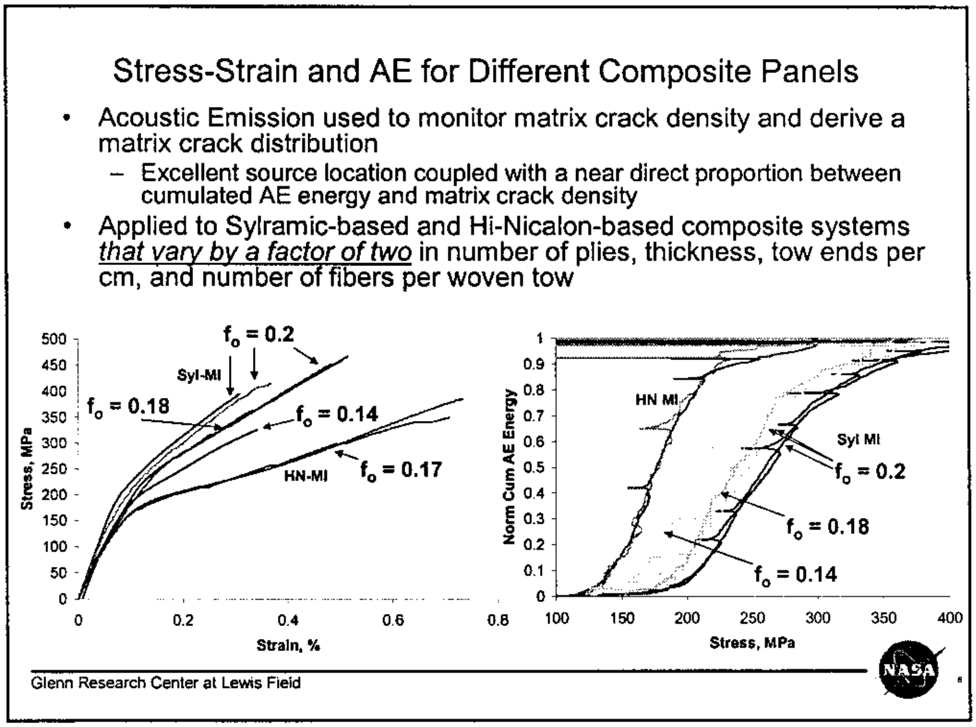
Furnace

MI SiC/SiC

2D Woven Systems When Stressed in Orthogonal Direction

HN and Sylramic (iBN) Fiber-types
MI and CVI SiC Matrix

Glenn Research Center at Lewis Field



Stress-Strain and AE for Different Composite Panels

- Acoustic Emission used to monitor matrix crack density and derive a matrix crack distribution
  - Excellent source location coupled with a near direct proportion between cumulated AE energy and matrix crack density
- Applied to Sylramic-based and Hi-Nicalon-based composite systems *that vary by a factor of two* in number of plies, thickness, tow ends per cm, and number of fibers per woven tow

Glenn Research Center at Lewis Field

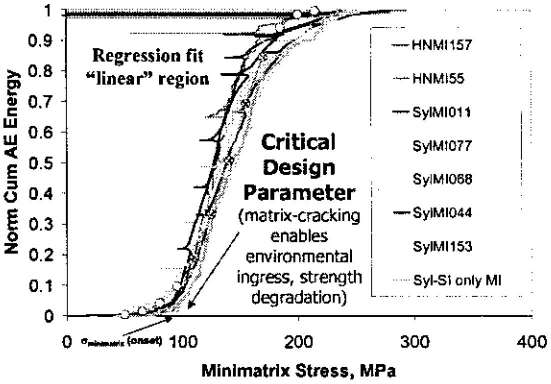
For Orthogonal Composites, the 90° Fiber-Tows are the Source for Matrix Crack Formation

- The stress that acts on the 90° fiber-tows is the stress in the composite "outside" of the load-bearing fiber, BN, CVI SiC minicomposite, i.e., the ***"mini-matrix" stress:***

$$\sigma_{\min imatrix} = \frac{\left(\overset{\text{Applied composite stress}}{\sigma_c} + \overset{\text{Net residual stress}}{\sigma_{th}}\right)}{\underset{\text{Composite modulus}}{E_c}} \left(\frac{E_c - f_{\min i} \overset{\text{0° minicomposite modulus (rule of mixtures)}}{E_{\min i}}}{1 - \underset{\text{Fraction of minicomposite in 0° direction}}{f_{\min i}}} \right)$$

All the information required is obtained from RT stress-strain test (or sound techniques) and processing data sheet.

A very simple relationship for matrix cracking in 2D MI SiC/SiC Composites



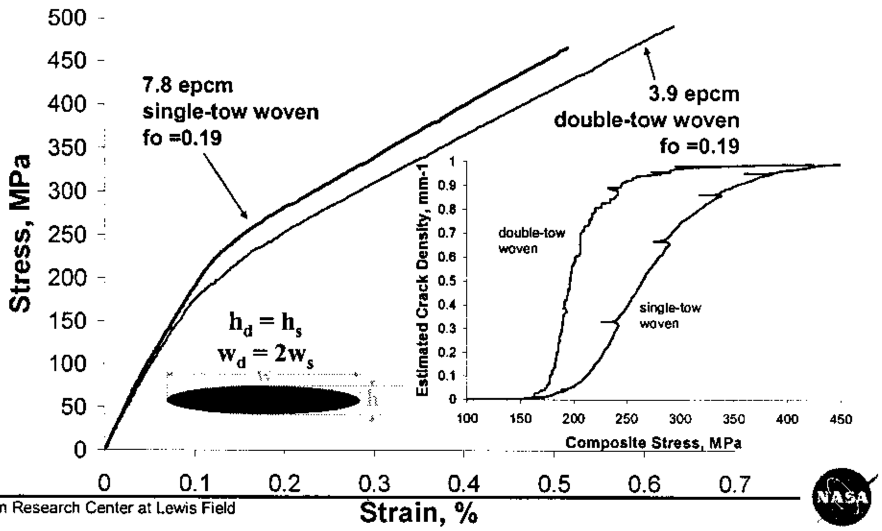
Critical Design Parameter (matrix-cracking enables environmental ingress, strength degradation)

ρ_c = final crack density
~ 2.5/mm for Hi-Nicalon
~ 10/mm for Sylramic
σ_o = 150 MPa; m = 5

$$\rho_c(\sigma_{\min imatrix}) = \rho_c \overbrace{\left[1 - \exp\left(- \left(\frac{\sigma_{\min imatrix}}{\sigma_o} \right)^m \right) \right]}^{\text{Norm Cum AE Energy}}$$

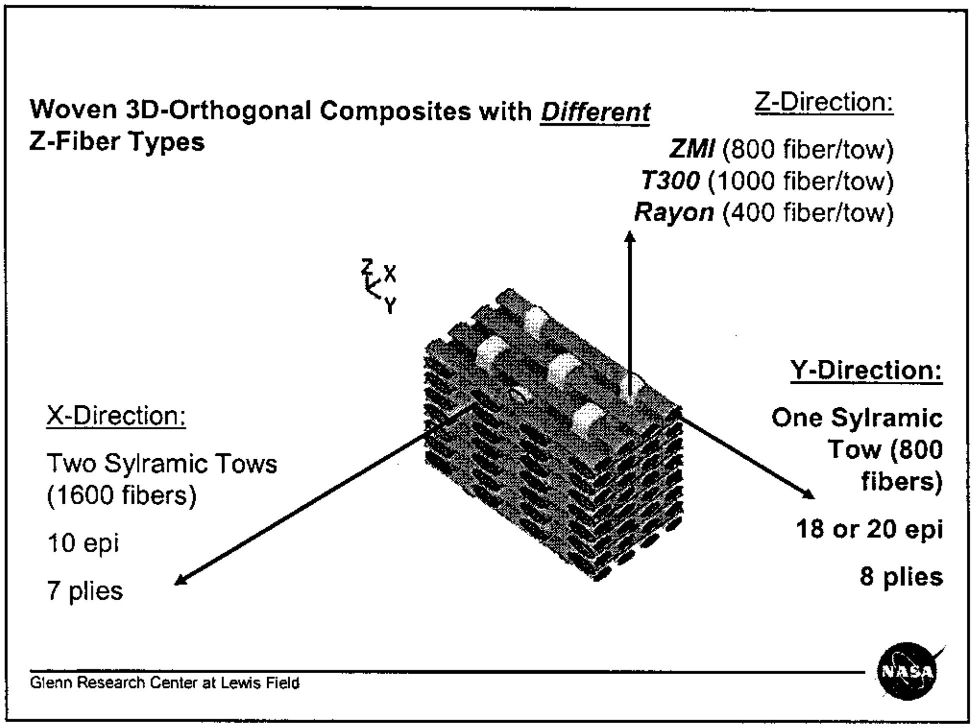
Effect of Tow Size and Shape:
Single-Tow vs. Double-Tow Woven Composites

- **Identical fiber volume fraction; Both five-harness satin**



3D-Orthogonal Composites With Different Z-Fiber Types

X- and Y-direction Fibers = Sylramic or Syl-iBN
MI Composites



Woven 3D-Orthogonal Composites with ***Different*** Z-Fiber Types

Z-Direction:

ZMI (800 fiber/tow)
T300 (1000 fiber/tow)
Rayon (400 fiber/tow)

X-Direction:

Two Sylramic Tows (1600 fibers)

10 epi

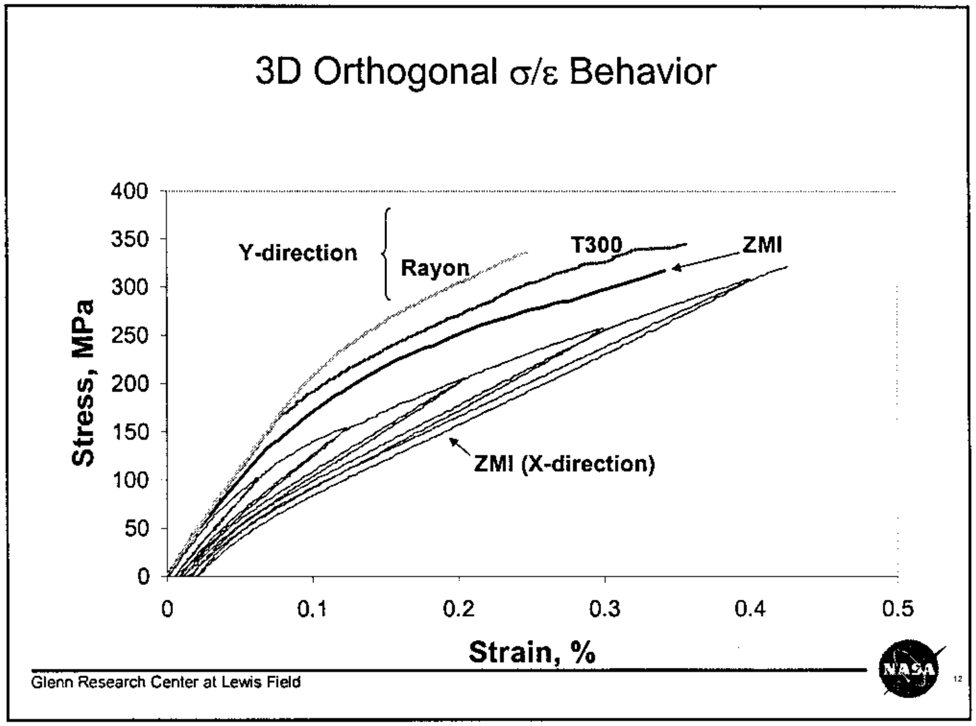
7 plies

Y-Direction:

One Sylramic Tow (800 fibers)

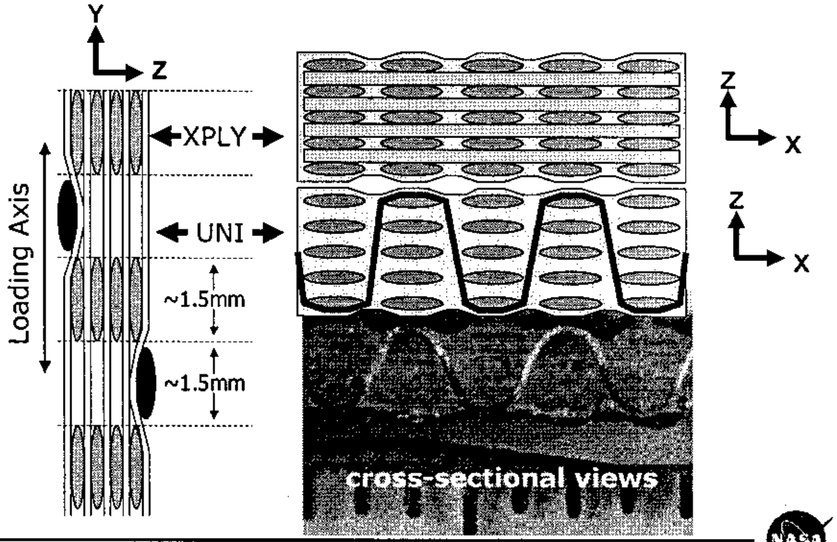
18 or 20 epi

8 plies



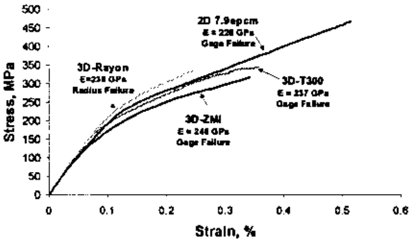
3D Orthogonal σ/ε Behavior

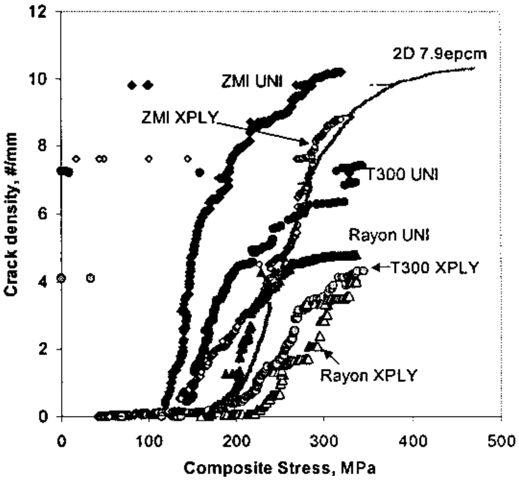
Loading in the Y-Direction

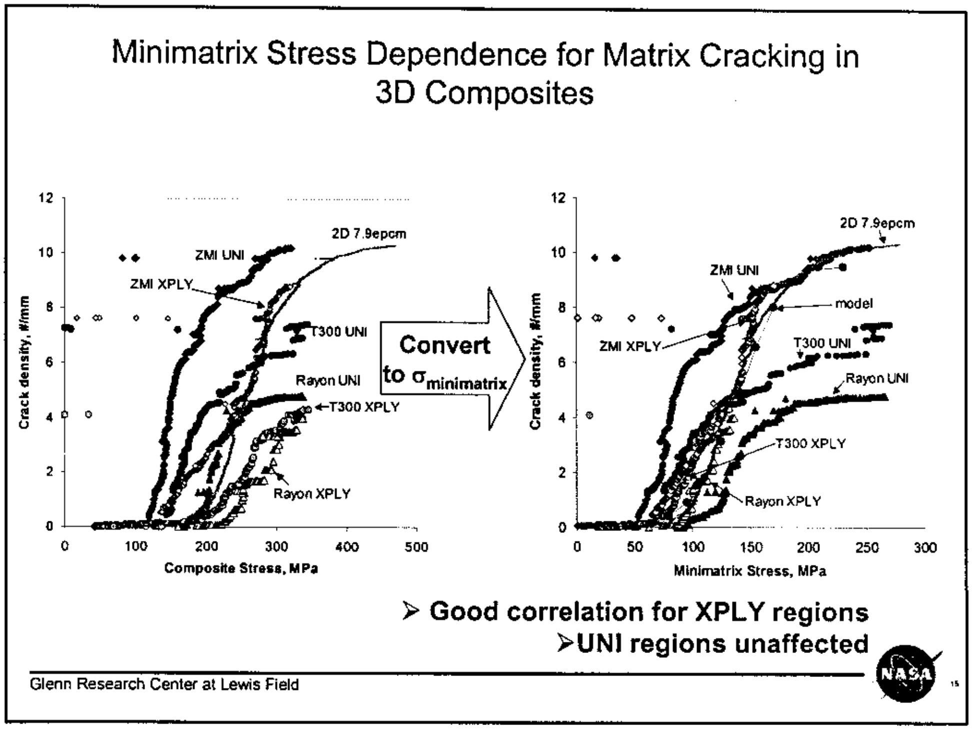


Stress Distributions For Three Y-Direction Oriented 3D Composites and Standard 2D Composite

- Wide range of matrix cracking stress-distributions
- XPLY cracking stresses always higher than UNI cracking stresses
- Rayon > T300 > ZMI

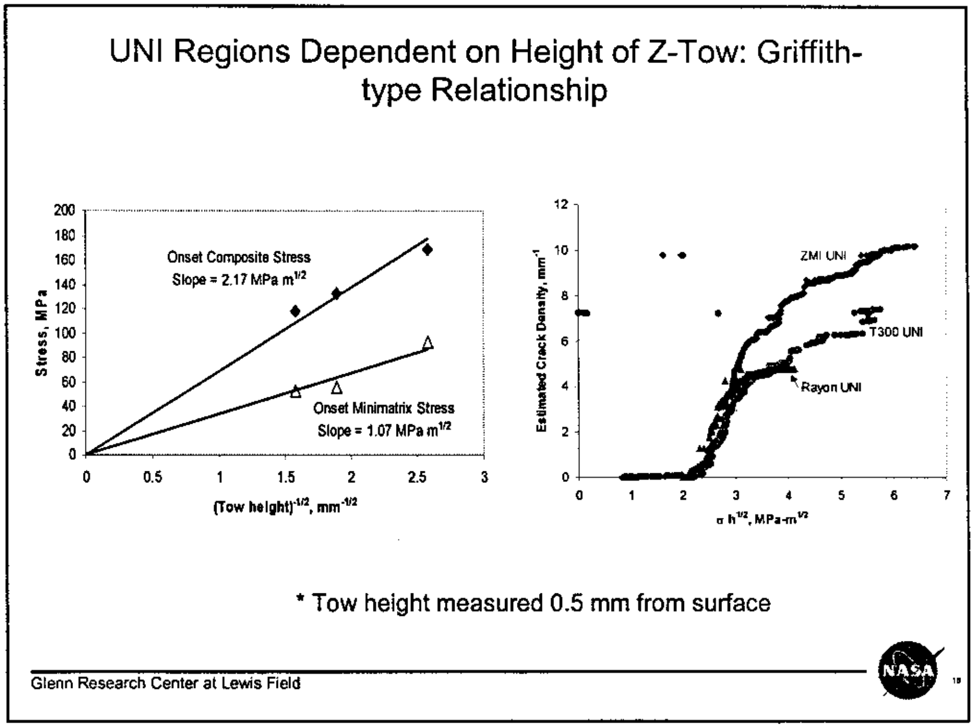






Minimatrix Stress Dependence for Matrix Cracking in 3D Composites

- ➤ Good correlation for XPLY regions
- ➤UNI regions unaffected



UNI Regions Dependent on Height of Z-Tow: Griffith-type Relationship

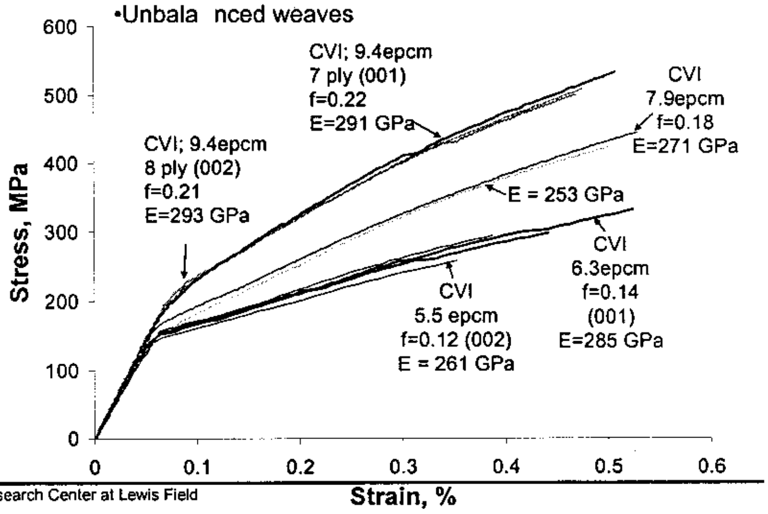
* Tow height measured 0.5 mm from surface

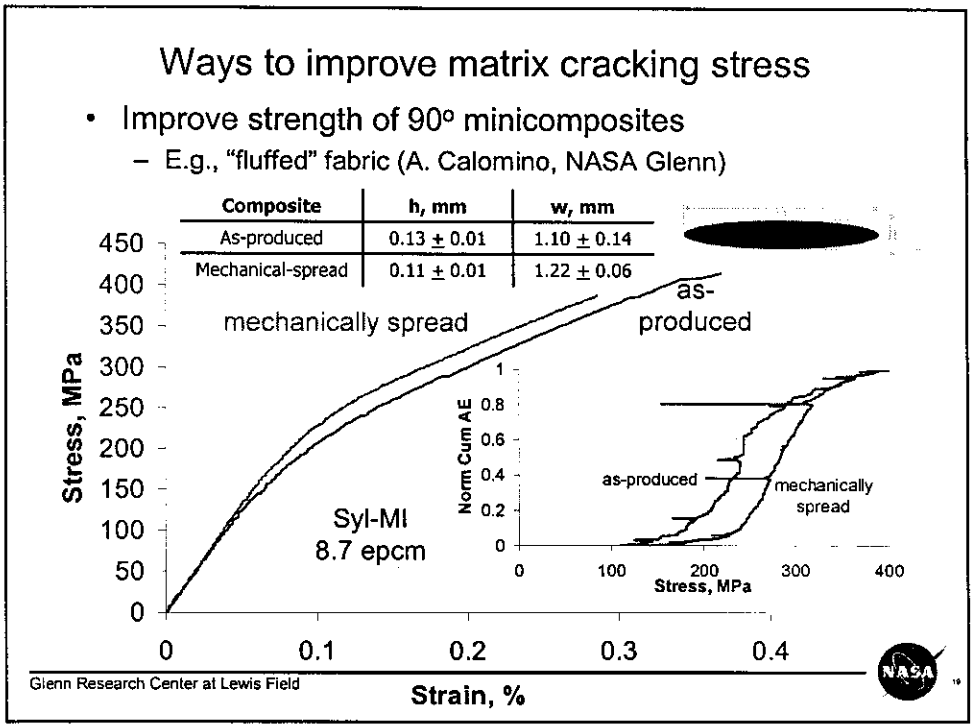
Ways to Increase Matrix Cracking Strength

Using the 2D Woven System

Ways to improve matrix cracking stress

- Optimize constituent contents
  - E.g., increase fiber volume fraction in loading direction
    - •Unbala nced weaves



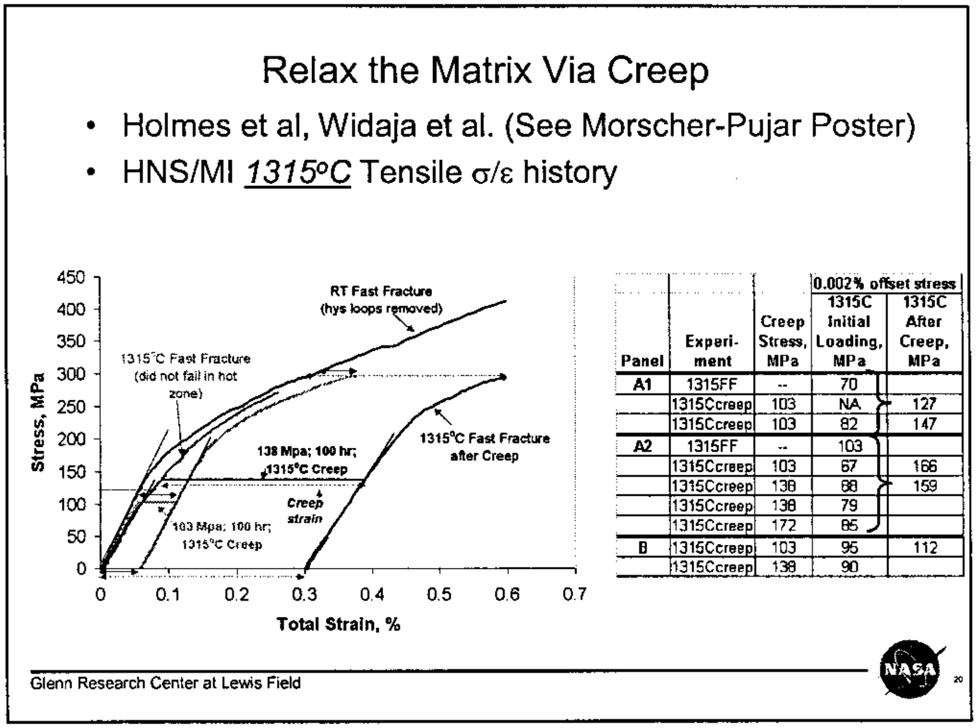


Ways to improve matrix cracking stress

- Improve strength of 90° minicomposites
  - E.g., "fluffed" fabric (A. Calomino, NASA Glenn)

Composite	h, mm	w, mm
As-produced	0.13 ± 0.01	1.10 ± 0.14
Mechanical-spread	0.11 ± 0.01	1.22 ± 0.06

Glenn Research Center at Lewis Field



Relax the Matrix Via Creep

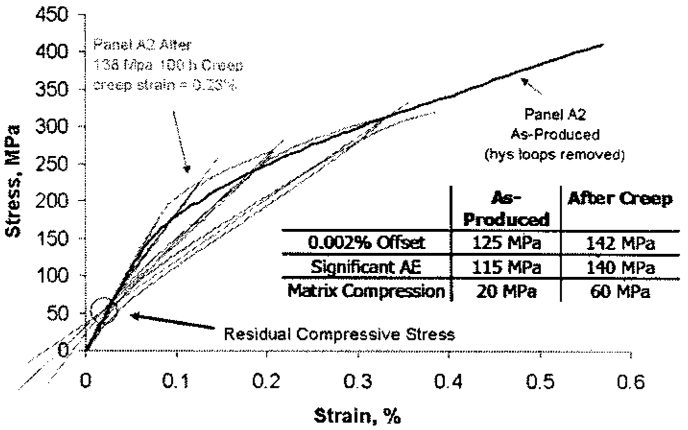
- Holmes et al, Widaja et al. (See Morscher-Pujar Poster)
- HNS/MI *1315°C* Tensile σ/ε history

			0.002% offset stress	
Panel	Experi-ment	Creep Stress, MPa	1315C Initial Loading, MPa	1315C After Creep, MPa
A1	1315FF	--	70	
	1315Ccreep	103	NA	127
	1315Ccreep	103	82	147
A2	1315FF	--	103	
	1315Ccreep	103	67	166
	1315Ccreep	138	88	159
	1315Ccreep	138	79	
	1315Ccreep	172	85	
B	1315Ccreep	103	95	112
	1315Ccreep	138	90	

Glenn Research Center at Lewis Field

Relax the Matrix Via Creep

- Holmes et al, Widaja et al. (See Morscher-Pujar Poster)
- HNS/MI *room temperature* tensile σ/ε after creep



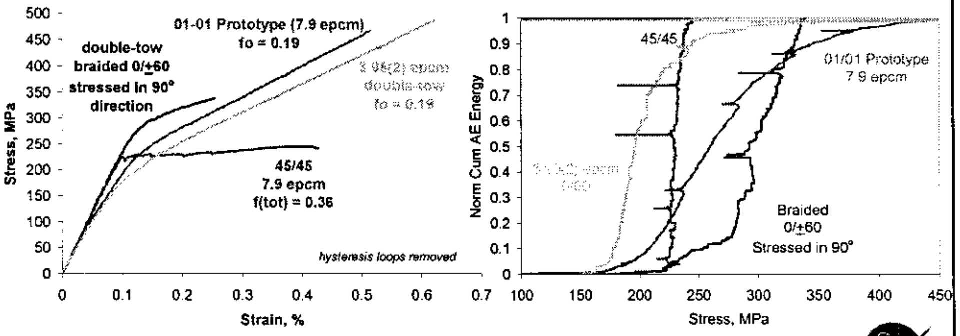
	As-Produced	**After Creep**
0.002% Offset	125 MPa	142 MPa
Significant AE	115 MPa	140 MPa
Matrix Compression	20 MPa	60 MPa

Off-Axis 2D Woven and Braided Architectures

Syl-iBN MI Composites

Matrix Cracking in Off-Axis Direction and for Braided Structure is Equivalent if not Better than Orthogonal Direction

- Limited data so far
- Note, double-tow woven, 0/±60 braided composite tested in the 90° direction



Summary and Conclusions

- The stress-distribution for matrix cracking in 2D and 3D orthogonal dense SiC matrix composites is dependent on architecture and can be effectively modeled with simple "minimatrix" approach
  - Mechanical behavior of 90° minicomposites and matrix-rich regions
- The stresses for matrix cracking in these systems can be optimized via architecture/processing enhancements
  - Fiber loading in desired direction
  - 90° tow dimension
  - Matrix relaxation via creep
- Onset of matrix cracking in off-axis directions is similar to orthogonal directions and is potentially superior for some architectures such as a braided structure
  - More optimization needed