Carbon Nano-Structure Infused Glass Fibers: The Future of Composite Materials?

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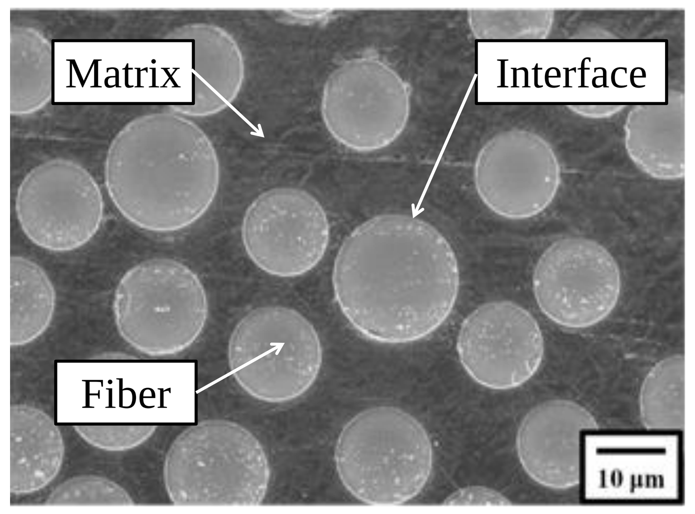
URCAD 2013

Introduction and Motivation

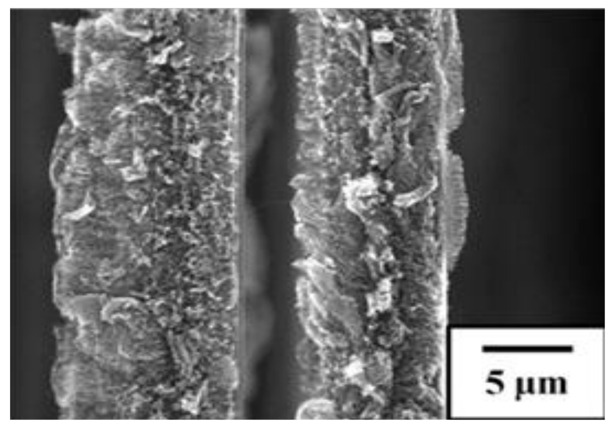
What is a Composite Material?

- Multiple phase material
- Reinforcing phase (fiber)
- Matrix phase (epoxy)



Carbon Nano-Structures (CNS) – Motivations

- High strength and stiffness, with a low density and an effective aspect ratio
- ***Harnessing CNS material properties as an additive to conventional fibers and epoxy systems to make multi-functional materials***
- Interface stress transmissibility increases seen with CNS coated fibers [1]



Background on CNS Processing

Chemical Vapor Deposition (CVD) – A Double Edged Sword

- Requires temperatures above the eutectic temperature (727 C) on the iron-carbon phase diagram
- Glass fibers undergo surface damage, known as pitting, when subjected to elevated temperatures which reduces the strength of the fiber [1,2]

Raises the question: Will performance increases at the interface overcome the strength degradation of the parent fiber?

Theoretical Model and Key Definitions

Kelly and Tyson Fiber Fragmentation Model [3]

$$\tau_c = \frac{\sigma_c}{2\left(\frac{l_c}{d}\right)}$$

Variables

- τ_c - The shear stress at the interface
- l_c - The critical fiber fragmentation length
- σ_c - The tensile strength of a fiber of gage length l_c
- d – The fiber diameter

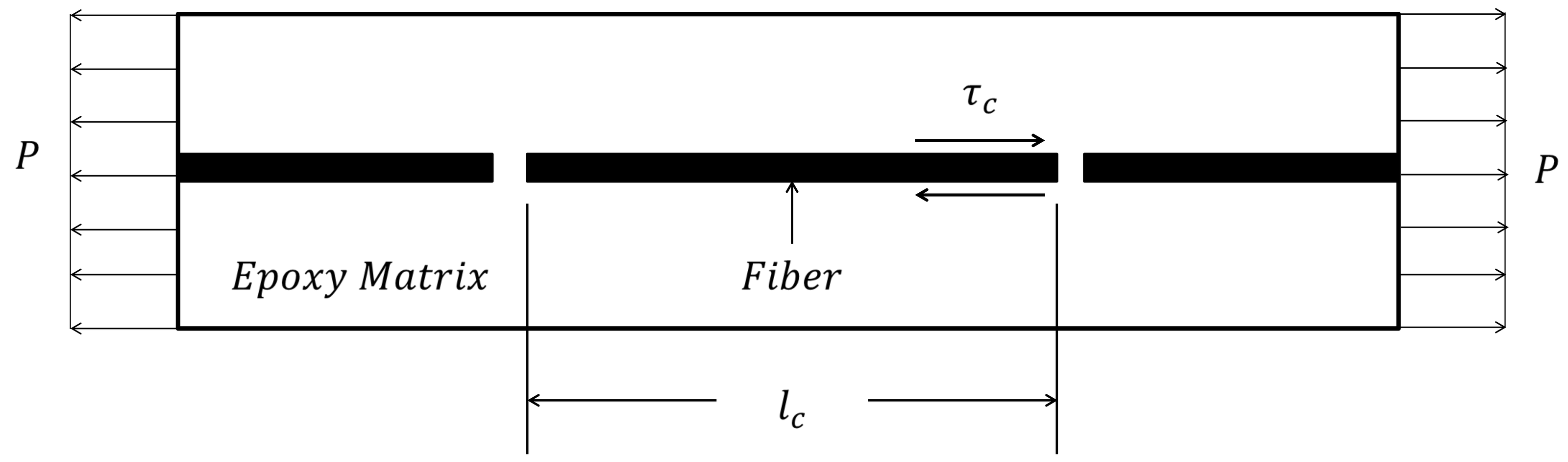
Assumptions

1. Constant fiber diameter, d, along the gage length
2. Constant tensile strength, σ_c, along the gage length

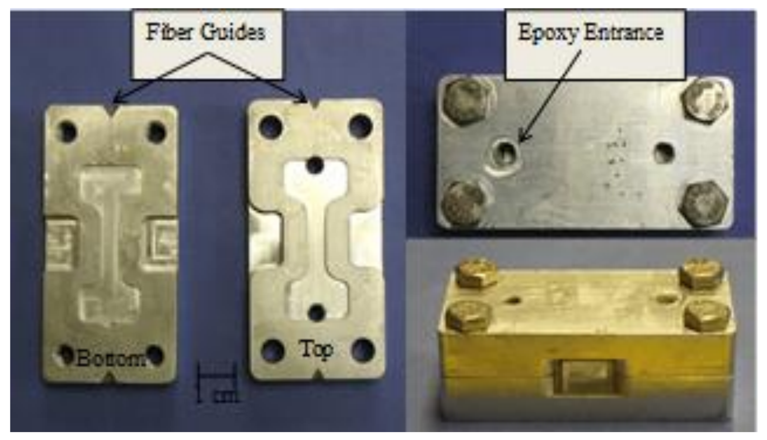
Methodology, Specimen Preparation, and Materials

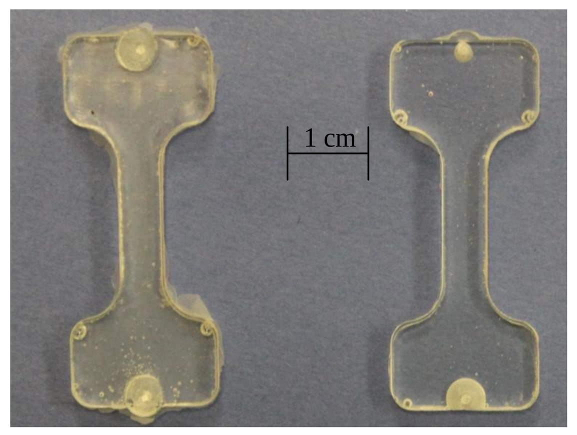
Single Fiber Fragmentation (SFF) Testing

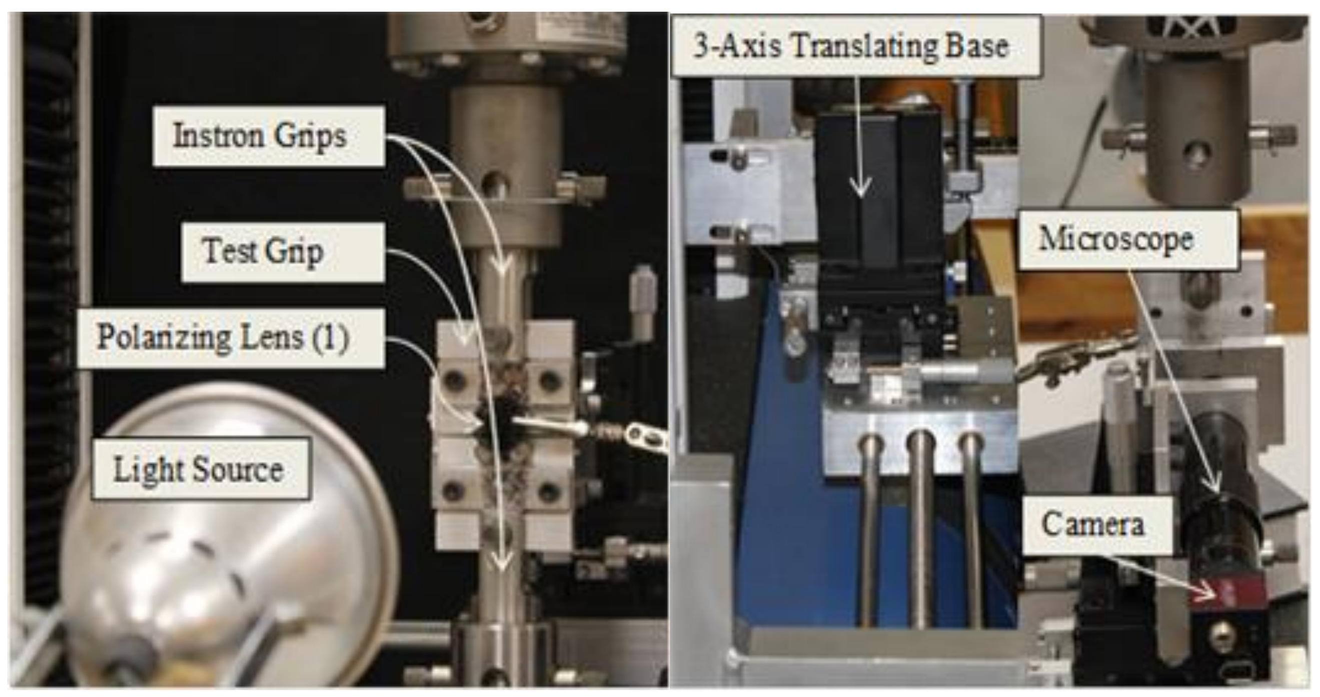
- Uniaxial tensile load applied
- Cross-polarized light to observe birefringence patterns (localized deformation of the matrix near the interface)
- Measurement of the fiber fragmentation lengths
- Evaluation of the critical aspect ratio l_c/d



Specimen Preparation





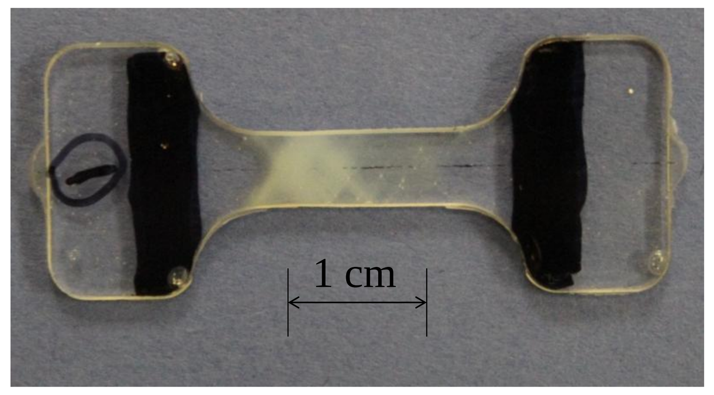


Fibers with Key Processing Parameters

Identification	Catalysis	Growth	Temperature °C
As-Received	None	None	None
Informed	Informing	None	None
CNS-Dip	Dip	Yes	725-750
CNS-Informed	Informing	Yes	725-750

- The catalyst used to stimulate CNS growth during the CVD process was a colloidal iron oxide

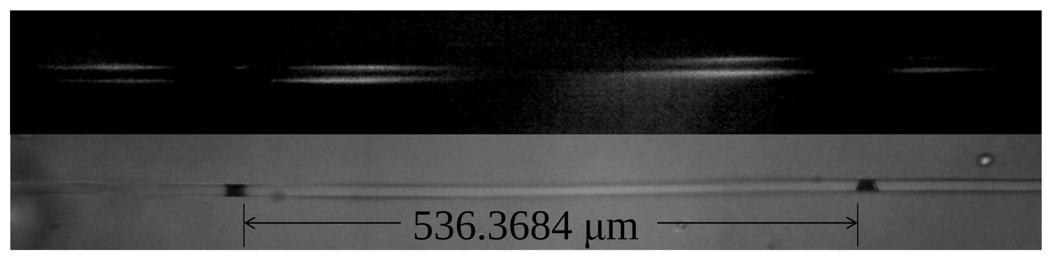
Results

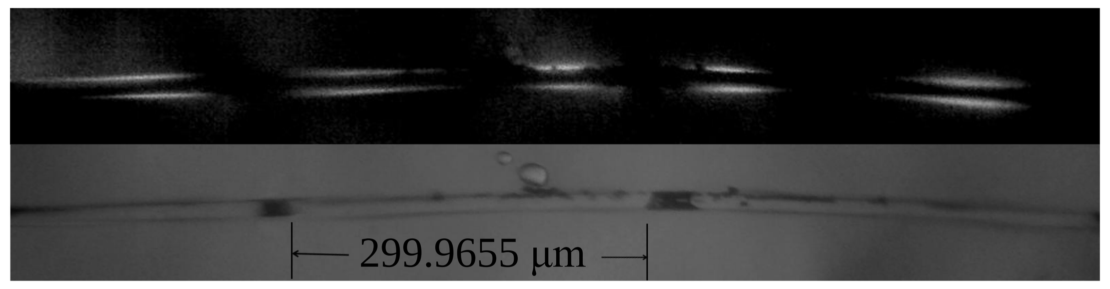


- Fragment measurements used to calculate critical aspect ratio
- Critical aspect ratio used to rank the composite systems

Identification by Catalysis	$\bar{d}$ (μm)	$\bar{l_c}$ (μm)	$\bar{l_c}/\bar{d}$	*Rank*
As-Received	9.02	386.08	42.79	4
Informing	9.42	553.49	58.76	6
Informing V2	12.87	560.69	43.57	5
CNS-Dip	10.84	323.44	29.84	1
CNS-Informing	10.92	340.57	31.18	2
CNS-Informing V2	14.17	453.43	32.01	3

As-Received Birefringence Pattern





CNS-Informing V2 Birefringence Pattern

Discussion and Conclusion

- Critical aspect ratio ranking is shortsighted
- Applying CNS onto fibers using CVD degrades the strength of the fiber
- ***CNS-infused fibers have the ability to create a unique material system that can be classified as multi-functional***

Current and Future Work

- Shear stress values at the interface were found: using this metric, the As-received performed the best, with the CNS-Dip performing second best
- ***Fibers coated in CNS solutions are the next generation of enhanced fibers that require characterization***
- New molds were built to combat the production of bubbles during the resin infusion process

Acknowledgments

This work was funded, in part, by the UMBC Office of Undergraduate Education through an Undergraduate Research Award, and Applied Nanostructured Solutions LLC, Baltimore, MD for the supply of fibers and CNS growth. Without both entities efforts, this work could not have been possible.

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Harnessing the properties of carbon nano-structures to build the materials of tomorrow.