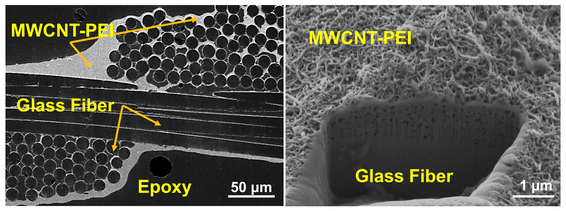
INTERFACIAL STUDY OF ELECTROPHORETICALLY DEPOSITED CARBON NANOTUBE COMPOSITE FILM IN HIERARCHICAL POLYMER COMPOSITES

Dae Han Sung[1,2] (Ph.D.M.E.), Dr. Sagar M. Doshi[1,2] and Prof. Erik T. Thostenson[1,2,3]*
University of Delaware | Center for Composite Materials[1] | Department of Mechanical Engineering[2] | Department of Material Science and Engineering[3]

Motivation

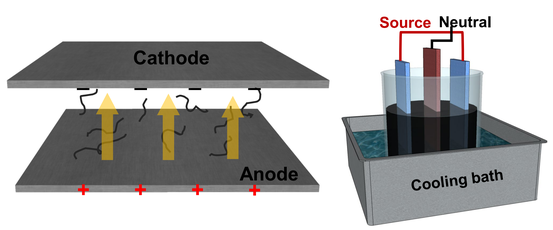
- Functionalized carbon nanotubes (CNT) coated by *electrophoretic deposition* (EPD) at fiber-matrix interface region modify the microstructure and *localized mechanical properties* of the hierarchical composites.
- Unique *porous nanocomposite structures* made by EPD provide permeable paths for resin infusion.
- Amine functional groups of polyethylene-imine (PEI) react with infused epoxy matrix.



Objectives

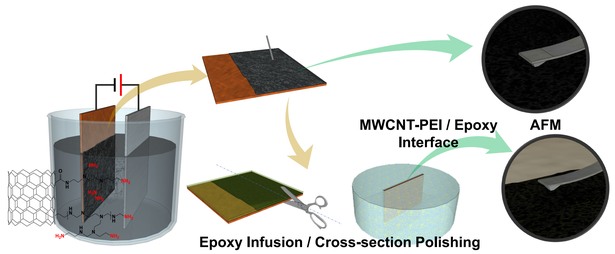
1. Fabricate uniform CNT-PEI/Epoxy nano-composite films for characterizing localized properties.
2. Characterize the CNT-PEI/Epoxy using atomic force microscopy (AFM) and compare with pure epoxy.
   - Tapping mode
   - Nanoindentation mode

Electrophoretic Deposition



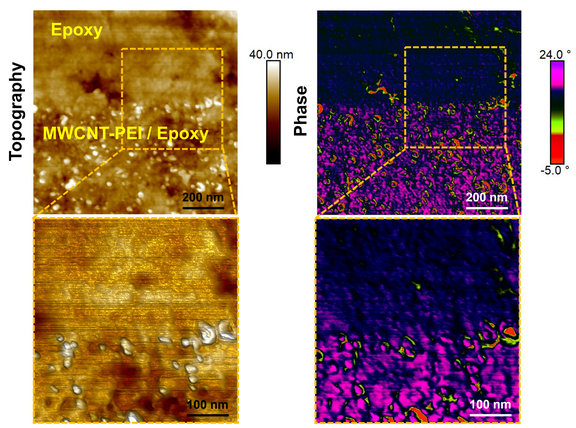
Key Advantages:
- Control over carbon nanotube purity and functionality
- Does not remove existing fiber sizing
- Room temperature processing
- No hazardous chemicals
- Stable and strong interfacial coating
- *Eco-friendliness* and *Scalability*

Materials and Methods



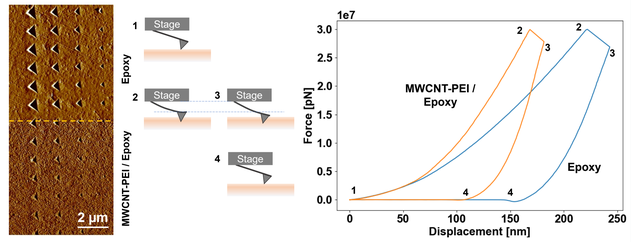
Electrophoretic deposition of PEI functionalized MWCNTs on copper tape, mimicking the nanocomposite films at fiber-matrix interface of hybrid composites.
- EPD conditions
  - Electric field strength: 10V/cm
  - Deposition time: 30min
  - Dispersion concentration: 1g/L
- Capable of tailoring the interfacial coating thickness by varying EPD parameters
  - Nanocomposite film thickness: 15-20μm

Interface Topography and Phase

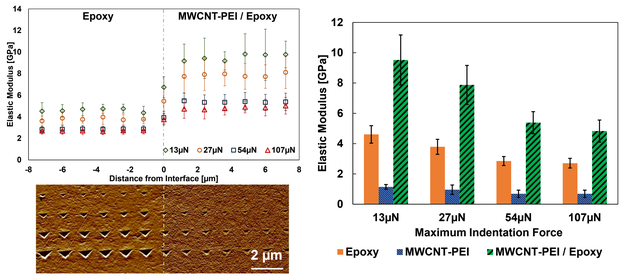


Atomic Force Microscopy – Tapping mode
- Interaction between the tip and sample surface causes the *phase shifting* or *lagging behavior.*
- MWCNT-PEI / Epoxy layers has higher lagging behavior about 2° as compared to epoxy.
  - PEI is resilient
  - Toughening effect

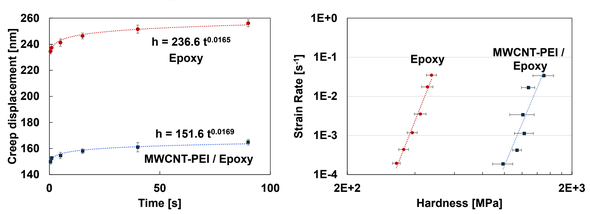
AFM Nanoindentation



Nanoindentation across Interface
- Slope of retraction curves represents the stiffness of materials.
- Holding (delay) time at the maximum indentation force was varied to analyze the creep behaviors of both regions.



Elastic Modulus Comparison
- Variation of the elastic modulus through thickness within MWCNT-PEI/Epoxy layer was not obvious, which means that epoxy resin was well *distributed/infused through porous* CNT structures created by EPD.
- The average modulus of CNT layer was approximately twice higher than epoxy matrix region.



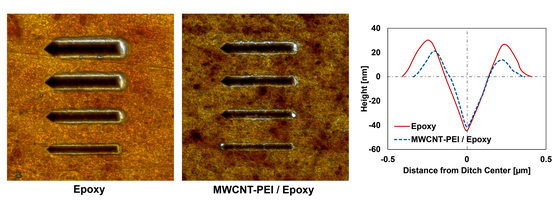
Creep Behavior Analysis
- The indentation strain rate corresponds to the ratio of the instantaneous descent rate of the indenter by the displacement.
- CNT nanocomposite film exhibited better creep resistance than epoxy due to the stiffened structure created by combination of MWCNT-PEI network and epoxy.

Key Conclusions

- Atomic force microscopy (AFM) was utilized to characterize the MWCNT-PEI / Epoxy interface.
  - Toughening effect of a functionalized polymer, polyethyleneimine (PEI), was observed from phase mapping, implying its energy absorbing behavior at the interface.
  - Chemical bonding between MWCNT-PEI and infused epoxy increased the elastic modulus approximately twice of epoxy alone.
  - Elastic modulus was consistent through the thickness of resin infused composite because porous structure was uniformly created by EPD.
  - MWCNT-PEI / Epoxy exhibited better creep resistance than epoxy.

Future Work

- Scratch test (AFM or nanoindentation)
  - Comparing frictional response of MWCNT-PEI / Epoxy film and epoxy matrix
  - Determining the dominating fracture mode/behavior under scratch



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