Engineered Polymer Composites Through Electrospun Nanofiber Coating of Fiber Tows

NASA Aeronautics Research Mission Directorate (ARMD)
FY12 Seedling Phase I Technical Seminar
July 9-11, 2013
Motivation/Impact

• Failure of advanced composite structures is often dominated by interfacial failure such as delamination.
• Local features such as holes, notches, and defects can cause failure of the composite at loads well below the fiber strength.
• Toughening of the material locally at the interface could dramatically improve the mechanical performance of the material without bulk modification of the matrix.
• This could lead to a relatively inexpensive way to improve performance without adversely affecting processing.
• Improved mechanical durability and strength would directly result in lower weight structures and improved efficiency in many applications such as engine fan blades.
Innovation and Technical Approach

- Develop a method for directly depositing thermoplastic nanofiber on continuous fiber materials for composite interface toughening.
- Build a machine capable of producing larger quantities of the coated material (1000’s of feet).
- Coat enough material to produce filament wound tubes for mechanical tests.
- Investigate possible interface toughening capability.
Factors in Electrospinning
- Solution viscosity
- Liquid solvent vapor pressure
- Ambient solvent vapor concentration
- Applied voltage
- Temperature
- Collector distance
- Polymer mechanical properties
- Solution conductivity
- Ambient gas flow conditions
Early Work

- GRC Fast Track demonstrated initial feasibility.
- ARMD Seedling provided opportunity to scale up to usable material quantities.

Polyethersulfone and DMF solution was electrospun using a ring of 8 needles onto carbon fiber.
Early Results

Significant beading was observed in the fibers and further work was needed.

A provisional patent was filed on June 15, 2012:
LEW 18844-1
Material Selection

- Towpreg consisting of 12k T700s carbon fiber with UF3325 resin was purchased from TCR Composites.
- The material has a 12 month shelf life at room temperature and can be cured as low as 132 Celsius. A cure at 143 Celsius for 2 hours was used.
- Nylon 11 was selected as the nanofiber toughener because of favorable mechanical properties, high melt temperature, and solvent resistance.
- A mixture of 3 parts dichloromethane and 1 part formic acid by weight was used to dissolve the Nylon 11.
- Different solutions were tried and a 2.5 % solution by weight was selected.
Electrospinning Machine

Grounding Pulley  Vent Pipes  Deposition Chamber  Purge Air Inlet  Wind/Unwind Stage

Purge Air Control  Solution Feed Control  Needles w/ Attached Reservoirs  Chamber Airlock  High Voltage Power Supply
Wind/Unwind Stage

- Lateral Stage
- Stepper Motor Driver, Wind Motor Driver not visible
- Wind Spool
- Quick Change Spool Holders
- Stepper Motor Power Supplies
- Microcontroller and Optical Sensors
Deposition Chamber

Vent Pipes
Purge Air Inlet
Airlock
Mounting Magnets
Air Tube
Solution Reservoirs
Carbon Fiber Towpreg passes through twice
Needles
High Voltage Connection
Modeling

FEA Modeling of Electric Fields with the Selected Needle Array
Nanofiber Deposition
Images of Coated Tow

Nanofiber on towpreg spanning a valley

Wetting of the nanofiber by the epoxy resin

Nylon 11 nanofiber mesh

Most of the nanofibers are between 100 and 300 nanometers. The fibers are very interconnected indicating that solvent was still present when they came in contact. Further process improvement may be needed.
Images of Coated Tow

Nylon 11 nanofiber mesh on the towpreg surface that has been pressed into the epoxy resin by the rollers.

Images were acquired by Scanning Electron Microscopy (SEM) at GRC.
Fabrication of Test Coupons

Filament Winding

Compression Specimens

Tension Specimens

+/45 Degree

90 Degree
Mechanical Testing

<table>
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<th>Architecture</th>
<th>Baseline 90</th>
<th>Modified 90</th>
<th>Baseline +/-45</th>
<th>Modified +/-45</th>
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<td>Post-Impact Compression</td>
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- +/-45 tension and compression will address Mode 3 shear of the interface.
- 90 tension will address transverse tensile strength.
- Post-impact compression will address resistance to damage propagation and distribution of damage due to impact loads through the thickness.

Tension Fixture
Accomplishments

• Scaled up the deposition method to a continuous process.
• Successfully electrospun Nylon 11 onto carbon fiber towpreg.
• Produced 1000’s of feet of nanofiber coated towpreg.
• Had filament wound tubes produced with baseline and coated material.
• Submitted a full patent application on June 14, 2013 titled “System and Method for Coating A Tow With An Electrospun Nanofiber.”
• Began mechanical testing which will be completed before the end of July, 2013.
Path Forward

• Additional work has been proposed that would focus on the selection and optimization of the nanofiber material and fracture toughness testing.

• Other nano-additives could be used in the precursor solution such as nanoparticles and nanotubes to provide a stable means of deposition while isolating the nano-material in the nanofiber.

• Wider continuous material could also be coated using this method.

• Properties other than toughness could be modified with this approach, including possibly thermal conductivity.
Thank you.

Presented by Dr. Lee W. Kohlman
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