SENSING OF RESIN FLOW AND CURE IN CONTINUOUS FIBER ADDITIVE MANUFACTURING

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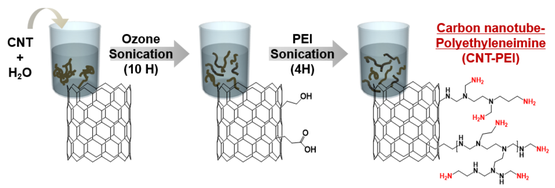
Introduction and Motivation

- Continuous fiber additive manufacturing is a cutting-edge technology with significant implications across various industries. The emergence of this technology has highlighted a need for real-time sensing during the manufacturing process.
- Carbon nanotube (CNT) is an instrumental material in nano-engineering for its novel electrical and mechanical properties. CNT coated substrates can be utilized as sensor to monitor stress, strain, structural health and different dynamic process of composite manufacturing.

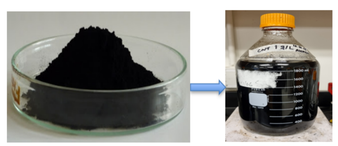
This research focuses on the use of functional CNT fiber coatings for use in *in situ* sensing of resin flow and cure during continuous fiber additive manufacturing.

Carbon Nanotube Functionalization



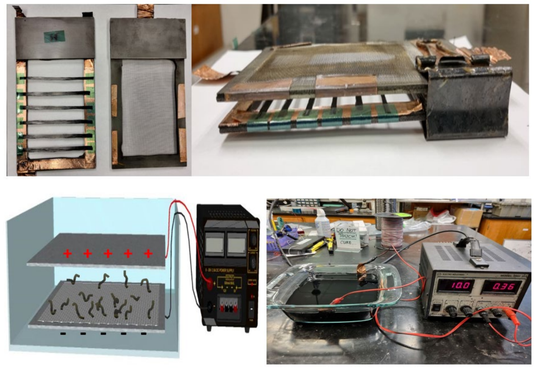
Functionalization

- Develop surface charge
- Provide mobility
- Form a stable dispersion
- Interfacial reaction with fiber/matrix



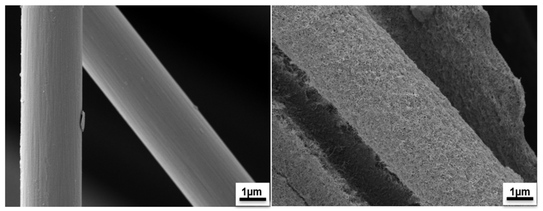
- Multi-walled CNTs were dispersed into ultra-pure water at a concentration of 1 g/L and was oxidized by ozonolysis for 16 hours maintaining the bath at 5°C.
- After the oxidation step, 2 grams of polyethyleneimine (PEI) was added into the ozone-treated dispersion followed by sonication for an additional 4 hours at 15°C to protonate CNT surface.

Electrophoretic Deposition (EPD)



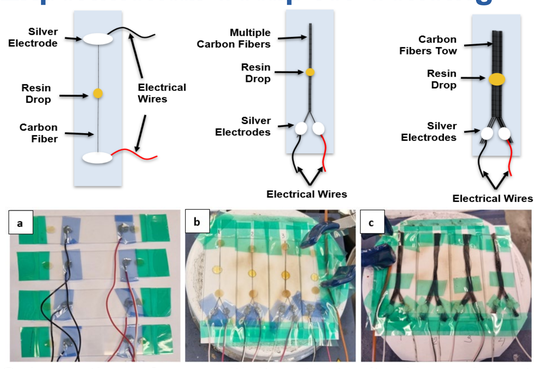
- Deposition of CNTs on to fiber bundles (top) and experimental setup of deposition process (bottom).
- EPD was conducted using a 1 g/L CNT dispersion under a field strength of 10 V/cm for 15 minutes.

Morphological Analysis



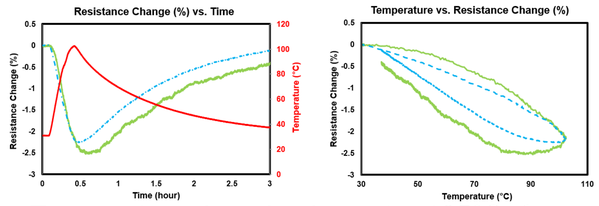
SEM micrographs of uncoated (left) and CNT coated (right) carbon fibera.

Experimental Setup for Sensing



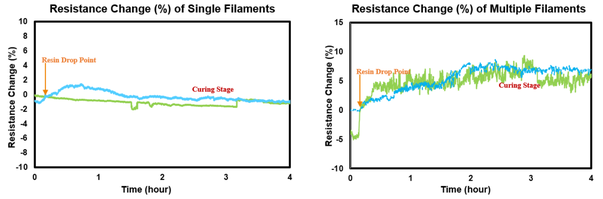
Schematic of sensitivity test (top) and actual experimental setup (bottom) of single filament (a), multiple filaments (b), and whole tow (c) of carbon fiber while resin infusion at 120°C.

Thermoresistive Sensing Behavior of Carbon Fiber



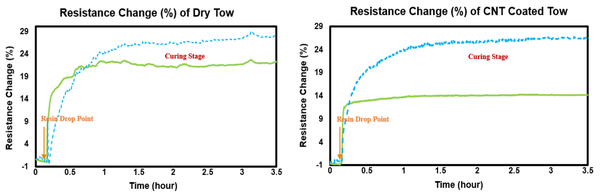
- Temperature is raised up to 105°C from room temperature without any interval and then lowered the temperature to room temperature
- 2.5% resistance change has been observed and hysteresis loop is seen upon cooling.

Sensing Response of Uncoated Carbon Fibers



- Single filament did not show significant resistance change after resin drop.
- After resin droplet multiple filaments showed (7-8)% resistance change and reached a plateau as curing progressed.

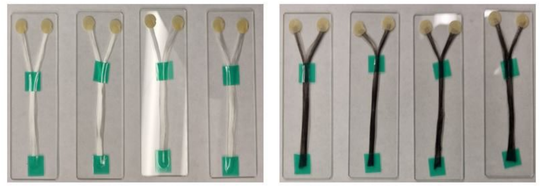
Sensing Response of CNT-PEI Coated Carbon Fibers



- Isothermal curing at 120°C.
- After resin infusion, CNT coated sample showed up to 26% resistance change.

Sensing Response of Glass Fiber

- In order to isolate the sensing response of the coating, non-conductive glass fibers were utilized as the substrate to examine the sensing response of CNT coating.



- After CNT coating, the glass fiber bundle became electrically conductive.
- CNT coated samples showed noticeable higher resistance change right after resin drop. Up to 30% resistance change was observed after resin drop on CNT coated samples.

Conclusions

- Carbon fibers showed distinct sensitivity to temperature. Both dry and CNT coated carbon and glass fiber showed noticeable sensitivity to resin infusion and curing.
- Development of resin cure kinetics model and mechanical properties of sensors will be studied as future work.

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