UTILIZATION OF CARBON NANOTUBE BASED SENSORS TO MONITOR RESIN FLOW IN RESIN TRANSFER MOLDING

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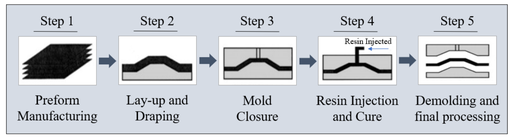
Introduction

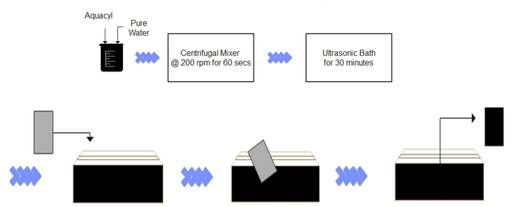
- The quality of the finished composite is very important and depends on various factors in the Resin Transfer Molding (RTM).
  - Vacuum vent's locations
  - Preparation of the fiber preform
  - Compatibility between the preform and mold walls



Resin Transfer Molding (RTM) Procedure

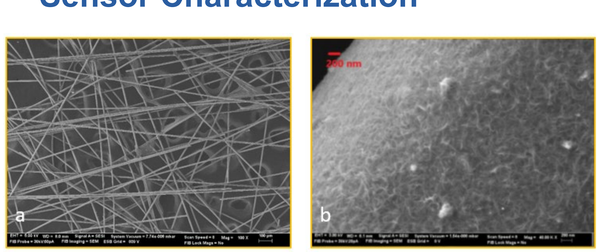
- Failing of any of these can result in race tracking which causes dry spots.
- As RTM is a closed mold technique to manufacture composites & the resin flow process is not visible through the molds, a control mechanism is required to detect any race tracking or defects during the injection and prevent it simultaneously.

Sensor Manufacturing



- Sensors were manufactured by depositing carbon nanotubes onto non-woven veils using a dip-coating method. The carbon nanotube (CNT) dispersion that was used to coat fabrics was prepared by mixing an aqueous sizing, where nanotubes and other polymers (AQUACYLTM AQ0303, Nanocyl) are dispersed.
- Coated veils were cut to the size of the composite part (3.5 in. x 5 in.) and for each sensing location, conductive silver paint (SPI Supplies ®, Structure Probe, Inc.) was applied.
- Wires were then attached to each electrode using a conductive epoxy (EPOXIES ® 40-3900, Epoxies, Etc.). Lastly, wire attached sensors were cured in oven at 80 degrees for 1 hour and kept in the oven overnight. The electrical resistivity of the conductive epoxy is very low with 0.0001 siemens/cm, thus can be ignored in calculations.

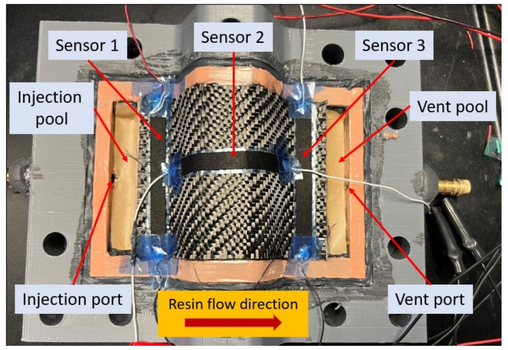
Sensor Characterization



(a) Low magnification CNT coated non-woven glass veil structure (b) Close up image showing random CNT distribution on a single fiber.

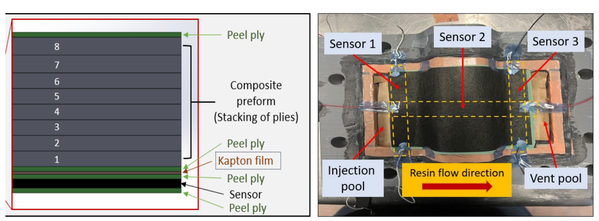
- The incorporation of CNT in the composite establishes an electrically conductive network, effectively transforming the fabric substrate into the foundational structure of a distributed sensor network.
- The sensing fabrics, enhanced with a coating of CNT, demonstrated baseline electrical resistance within the range of 50Ω to 2 kΩ.
- The coated glass veils 10 g/m^2 exhibited a random non-woven structure.
- CNTs are randomly distributed on glass fibers and creating a uniform electrically conductive network.

Experimental Setup



CNT stripe sensor placement on carbon fibers before closing the mold

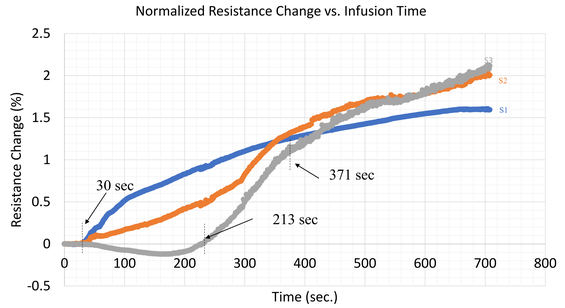
- In the preliminary experiment, three stripes of sensors made from CNT-coated glass veil, each measuring 8.89 cm x 1.27 cm (3.5 inches x 0.25 inches), were fabricated.
- To electrically isolate the sensors and conductive carbon fibers, a tape was applied between two layers.
- When the finished composite part was demolded, an undesirable effect on the part was noticed where the sensor tape touched the part. Stripe sensors created a thickness variation throughout the part, and resin accumulated around the sensors in the fabricated composite.



Ply stack configuration (left), and CNT veil sensor placement on carbon fibers before closing the mold (right)

- A layer of sensor ply was fabricated and a layer of Kapton film was placed to electrically insulate the CNT sensors and carbon fibers.

Results and Conclusion



Normalized resistance change ($\frac{R_j - R_0}{R_0} x100$) of 3 sensors during RTM

- The instant the resistance starts to increase signals the arrival of the resin there. When the resin reaches S1, which is the sensor near the injection port, the slope of the increase of S1 is steeper because the entire sensor area is covered. S2, the sensor covering the region between the injection and the vent, the increase in resistance is slower as resin continues to cover the S2 region until it reaches the vent. Then, , resistance of S3 started to increase, indicating that the resin arrived at sensor 3.
- Results indicate the sensor measurements were in line with the observation, and there were no drastic changes in the resistance during the infusion which demonstrated complete electrical isolation of the sensors
- The curved carbon fiber composite part has been successfully manufactured with integrated sensors and were able to detect the times resin reached sensing areas.

Acknowledgements

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