Nondestructive Evaluation of Low Velocity Impact Damage in Polymer Composites: Assessing Damage Parameters using Near Infrared Spectroscopy

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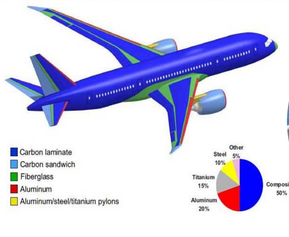
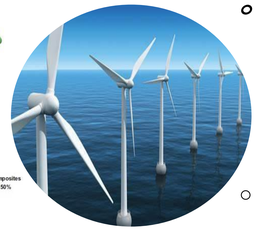
Creating a Safer World

Composite Response and Characterization Lab

Introduction and Theory



Material Composition of Boeing-737 Dreamliner

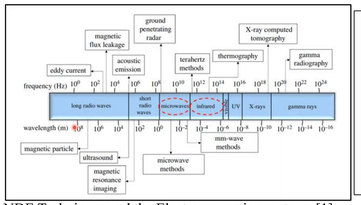


Wind Turbine Applications

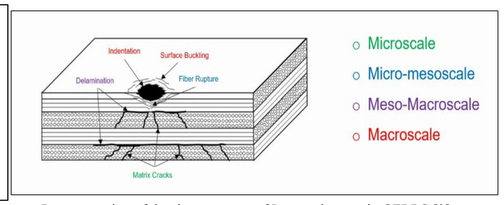
- ***Polymer Composites***: A blend of two different kinds of engineering materials (Polymer matrix and a fiber reinforcement) to form a new one with properties better suited for the desired application.
- Composite adoption continues to gain traction in critical infrastructures.
- We want **Light weight!**

Problem Statement and Motivation

- Low Velocity Impacts can create barely visible impact damages (BVID).
- This kind of damage may not be seen easily and can propagate to cause failure.
- Damage Evolution, particularly in composites is complex.

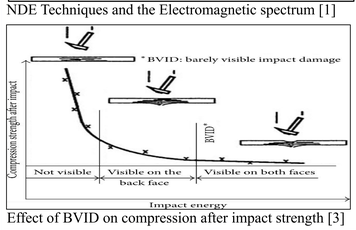


NDE Techniques and the Electromagnetic spectrum [1]

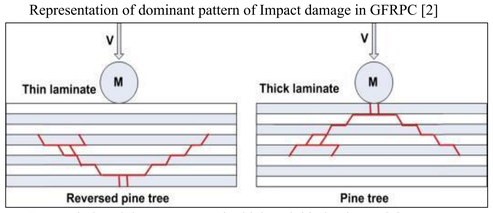


- Microscale
- Micro-mesoscale
- Meso-Macroscale
- Macroscale

Representation of dominant pattern of Impact damage in GFRPC [2]



Effect of BVID on compression after impact strength [3]

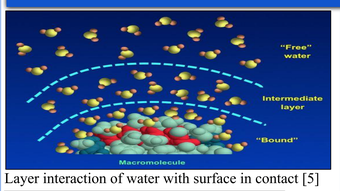


Impact-induced damage pattern in thick and thin laminates [4]

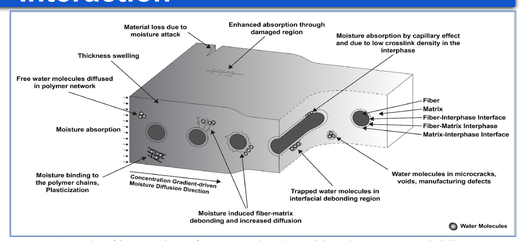
❑ **Motivation**

- Moisture contamination is inevitable for **in-service polymer composites .**
- The amount of moisture absorbed is facilitated by level of damage.
- Hence, we use moisture as a molecular fingerprint to detect and quantify damage at the micro scale before visible cracks.
- **Absorbance Area** and **Free-to-Bound water ratio** from **NIR Spectra** are parameters of interest.

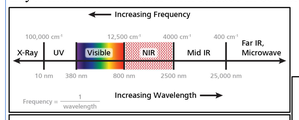
Near Infrared Spectroscopy and Polymer-Water Interaction

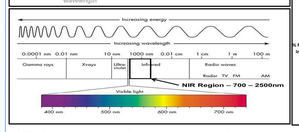


Layer interaction of water with surface in contact [5]

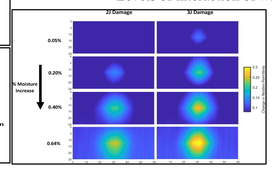


Levels of interaction of water molecules with polymer network [6]

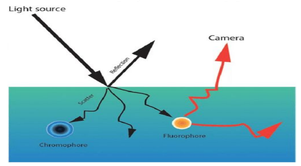




NIR Region in the Electromagnetic Spectrum

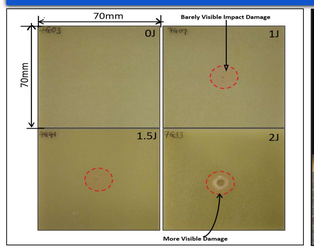


Dielectric Spectroscopy [7]

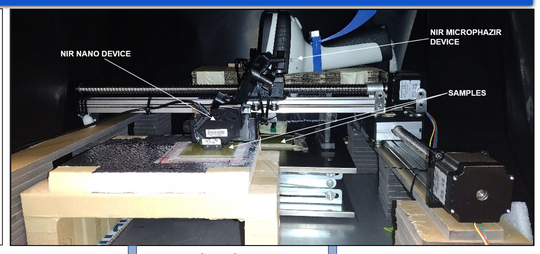


Near Infrared Spectroscopy

Methods and Experimental Setup

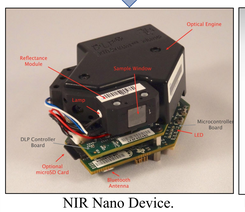


Test samples with 0J, 1J, 1.5J and 2J damage



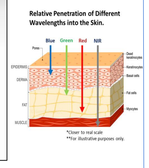
Scan Setup

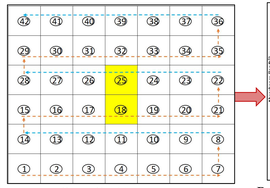
Drop Tower Setup for inducing BVID.



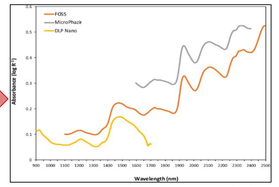
NIR Nano Device.

Microphazir NIR Device.





Scan Grid layout



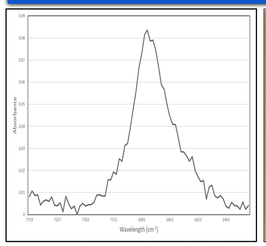
Raw spectra measured by three NIRS devices

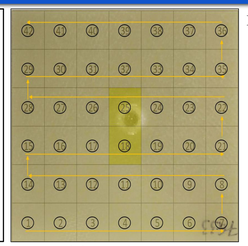
- Samples impacted at different impact energy using the drop tower.
- 7 x 6 grid points, 10mm x 10mm step size.
- **Nano-NIR and NIR Microphazir used in diffuse reflectance mode.**
- Wavelength range between 900-1700 nm (NIR Nano) and 1600-2400 nm (NIR Microphazir).

❑ **Scanning Process with the Near Infrared Spectroscope Setup**

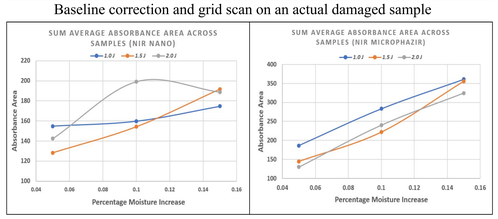
- Samples dried and scan for reference values before introducing low velocity impact.
- Samples scanned with both the NIR Nano and Microphazir device to obtain absorbance vs wavelength spectra.
- Process region of dominant moisture activity where spectrum can be separated into free/bound moisture.
- Baseline correction and dry subtraction to mitigate confounding factors.
- Composite structures have **locally elevated spectra peaks signatures** near the damage sites.
- **Absorbance Areas** obtained from **NIR Spectra (Nano and Microphazir)**

Results



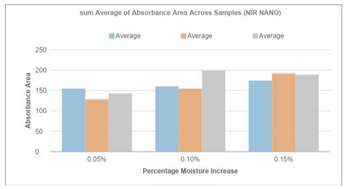


Baseline correction and grid scan on an actual damaged sample

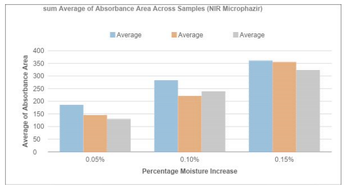


Comparison of sum average of absorbance area values with increasing moisture content (by wt.) and levels of impact damage (a) 0.05% (b) 0.10% (c) 0.15% moisture (by wt.)

Effects of damage and moisture on Absorbance Area for NIR Nano vs NIR Microphazir (1.0J, 1.5J, 2.0J)



NIR Nano Plots at 0.05% - 0.15% moisture content (by weight)

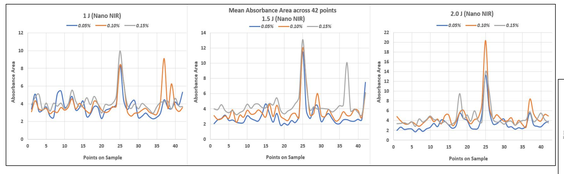


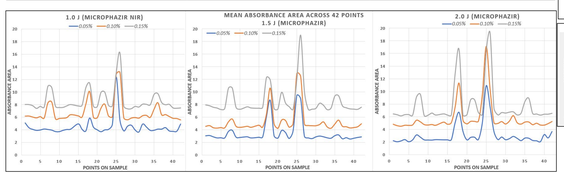
NIR Microphazir Plots at 0.05% - 0.15% moisture content (by weight)

Results and Discussion

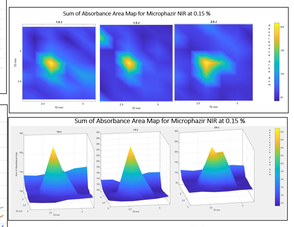
❑ **Effects of Impact Damage and Moisture level on Absorbance values**

- Relationship between spectral plots and impact energy of damage is not always linear.
- Increased moisture content helps to distinguish peaks.
- Area under the spectral curve increases with increasing level of impact damage.





Absorbance plots at 0.05% - 0.15% percent moisture content (by wt.) for increasing levels of damage (1J, 1.5J and 2.0J)



Absorbance Area maps of 1.5 J damage sample: (a) 2D map (b)3D map.

❑ **Variation of Absorbance area across samples**

- Absorbance area values remain close at points where there is "no damage" (depicted with blue coloration in the map) and significantly higher at points where the impact damage is higher (depicted in the map as yellow gradient).
- Sites with more damage (toward the center of the sample) have higher absorbance area values while further away from the center of the sample have lower values of absorbance area indicating the presence of moisture.
- Both the NIR Nano and the NIR Microphazir instruments showed promise in detecting and measuring impact-induced damage in the polymer composites.

Conclusions

- Both the NIR Nano and the NIR Microphazir instruments showed promise in detecting and measuring impact-induced damage in the polymer composites.
- Differences exists in terms of resolution and quantitative analysis capabilities.
- Absorbance area can be used as a quantitative parameter for composite damage characterization.
- The NIR Microphazir is more promising for quantifying damage than the NIR Nano device.
- Some points with unexpected peaks may provide information about the molecular activity of moisture in those areas.
- Composites' reliability in the industry can significantly improve through further development of this technique.

Ongoing and Future Work

- 2D Deconvolution of NIR spectral curves for free/bound water quantification
- Compare NIRS technique with Phased Array Ultrasonics (One of the major Aerospace industry NDT techniques)
- Quantitative NIR models to quantify and predict damage based on Absorbance area and free/bound water ratio values.
- Probe penetration depth to determine the penetration depth of both NIR Nano and Microphazir.
- Apply ML techniques to predict and quantify damage based on proposed parameters.

References

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[3] M. Ali, S. C. Joshi and M. T. H. Sultan, "Palliatives for Low Velocity Impact Damage in Composite Laminates," Advances in Materials Science and Engineering, vol. 2017, pp. 1-16, 2017.
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