PhD Dissertation Defense Announcement
Mechanical and Aerospace Engineering Department
University of Texas at Arlington

A MULTIMODAL PREDICTION FRAMEWORK FOR MOISTURE AGING ASSESSMENT IN POLYMER MATRIX COMPOSITES

By

PARTHA PRATIM DAS

Advisor: Dr. Rassel Raihan

12:00 PM, Monday, November 17, 2025
Woolf Hall, Room 413

Abstract

Polymer matrix composites (PMCs) offer outstanding strength-to-weight ratios but remain vulnerable to environmental degradation, particularly moisture absorption. Absorbed water alters polymer chain chemistry through plasticization and molecular bonding, resulting in reduced mechanical and dielectric integrity. To account for the limited understanding of the underlying absorption mechanisms, engineers adapt to conservative design methodology, assuming a composite structure is already saturated with moisture, while it is not. This dissertation presents a unified experimental, computational, and physics-informed machine learning framework for modeling and predicting moisture-induced degradation in glass fiber–reinforced polymer (GFRP) composites. In this study, Broadband dielectric spectroscopy (BbDS) was first used to identify polarization mechanisms and dielectric permittivity associated with moisture absorption. The dielectric permittivity and relaxation strength increased with exposure time and stabilized at saturation, correlating strongly with moisture concentration and reductions in tensile and flexural strength. This established dielectric sensing as a viable non-destructive tool for assessing moisture-related damage. Data-driven Machine learning models were then developed to estimate the composite's moisture content from its dielectric response. Supervised classification and regression models, including support vector machines and multilayer perceptron networks, accurately predicted the material's saturation state with coefficients of determination above 0.95, revealing the dielectric features most sensitive to hygrothermal aging. Then, a multiscale–multiphysics finite-element framework was developed to mechanistically couple moisture transport and dielectric property evolution. The non-Fickian hindered diffusion model (HDM) distinguished free and bound water diffusion, incorporated interphase heterogeneity, and linked the resulting moisture fields to Maxwell's electromagnetic equations. The coupled HDM–Maxwell model captured experimental trends, showing that a ~2.5 wt% moisture uptake produced a ~75 % increase in dielectric permittivity. Finally, a physics-informed neural network (PINN) was developed to solve the coupled HDM–Maxwell system. Using Modified Fourier architectures, signed-distance weighting, and adaptive residual balancing, the network achieved over six orders of magnitude loss reduction and good validation accuracy. Thus, the framework establishes a mechanistic understanding of moisture diffusion, molecular binding, and dielectric behavior, providing a scalable foundation for digital-twin-based monitoring and lifetime prediction of advanced polymer composites.