Physics-Informed Artificial Intelligence for Non-Destructive Evaluation of Ceramic Composite Cladding by Creating Digital Fingerprints

PI: Joel B. Harley – University of Florida, Gainesville, FL

Collaborators: Dr. Ghatu Subhash (Co-PI) – University of Florida, Gainesville, FL

Dr. Deck Cristian (collaborator) – General Atomics, San Diego, CA

Program: FL-1: ACCIDENT TOLERANT FUELS

ABSTRACT:

This project creates an innovative non-destructive evaluation (NDE) assessment system for SiC_f-SiC_m cladding tubes. To accomplish this, we complete three objectives: (1) Establish an innovative physics-informed machine learning (PIML) to measure digital fingerprints of highly anisotropic and heterogeneous composites by advancing robust mathematical algorithms that learn spatially dependent mode shapes and anisotropic dispersion relations directly from experimental data; (2) Experimentally build a database of digital fingerprints from laser Doppler vibrometer measurements of SiCf-SiCm composite cladding with a wide variety of manufacturing defects; and (3) provide a functional and validated design of a non-destructive evaluation tool, using a scanning laser Doppler vibrometer for on-line inspection and rapid extraction of fingerprints in a manufacturing setting.

Unlike other characterization tools (such as microscopy, tomography, and spectroscopy), ultrasound technology is relatively inexpensive, fast, and portable, enabling broad applicability, including in extreme environments. The primary challenge is that the ultrasonic spatial-spectral characteristics (i.e., our fingerprints) that define the anisotropic and heterogeneous relationships are difficult to decipher and difficult to extract. This project creates algorithms and theories to assess such characteristics directly from experimental data, which expands on the PI's prior work and expertise. To accomplish this, we propose seven tasks: manufacture our test specimens, perform validation measurements with expensive and bulky x-ray computerized tomography and Raman spectroscopy, create our proposed rapid NDE prototype for inspection during manufacturing, and establish the PIML framework to learn the digital fingerprints of as well as detect and characterize defects in our specimens. The final task quantifies the uncertainties due to the manufacturing process and/or our machine learning algorithm.

The impact of this effort benefits the goal of enabling a faster and more reliable SiC_f-SiC_m cladding tube manufacturing process. In addition, the proposed approach is fundamentally new for modeling wave propagation, specifically for anisotropic and heterogeneous woven composite materials and NDE applications. It provides fundamental insights into how ultrasonic NDE systems can be applied for quality control of complex material systems. The proposed formulation creates an algorithm that advances the state-of-the-art in NDE using ultrasound technology by combining the latest advances in PIML to characterize materials faster and at a lower cost than previously possible. Finally, we will develop technology (a tool) for *online* inspection of manufacturing processes and rapidly characterizing materials and their defects.

The effort is a collaboration between the University of Florida (UF) and General Atomics (GA). The UF is responsible for the creation of the functional scanning laser doppler vibrometer, the PIML framework for rapid NDE, and the validation of the proposed framework. The industry collaborator (GA) is the world leader in the manufacture of SiC_f-SiC_m composite cladding tubes. They will manufacture our specimens and provide insights into the material characteristics for implementing and validating the PIML framework and insights into the manufacturing process in creating the on-line inspection system. The team has the necessary experience and equipment to complete the stated objectives successfully.