
Graphite Microstructural Characterization using Time-Domain and Correlation-Based Ultrasonics

PI: James Spicer – Johns Hopkins University

Collaborators: Glenn R. Romanoski – Oak Ridge
National Laboratory, Dennis C. Nagle, Johns Hopkins
University

Program: NGNP-2

ABSTRACT: Under this program, a range of ultrasonic nondestructive methods will be developed to assess microstructural characteristics of nuclear grade graphites including those subjected to thermal cycling and/or neutron irradiation. Since laser ultrasonics methods have proven to be effective for characterizing nuclear grade graphites, these will be used and will be correlated with microstructure by characterizing materials using standard techniques including x-ray diffraction, scanning electron microscopy, transmission electron microscopy and porosimetry. Under this program, three different laser-based ultrasonics approaches to bulk, microstructural characterization of nominally isotropic, nuclear grade graphites will be pursued: effective medium, multimode ultrasonics for assessment of microcrack and void densities; shear birefringence measurements for determination of microcrack density and orientation distribution; ultrasonic scattering correlation measurements for defect distribution determination. Effective medium descriptions for materials can be conveniently formulated under situations in which the behaviors of microstructural elements such as porosity and cracks can be defined in terms of their effects on the energy state of the material. Under these circumstances, their presence simply alters bulk properties. For microcracks, stress state energies can be described using established fracture mechanics approaches (J -integral) and the effective material stiffness can be calculated directly if ultrasonic wavelengths are large compared to crack dimensions. This type of effective medium approach can be used to quantify the expected variation of elastic stiffness with microcrack densities. A subset of the effective medium approach will be pursued to determine preferred orientation of voids and microcracks by noting induced anisotropy. Preferred grain orientation in a material (texture) can result in generation of microcrack and void distributions that also have preferred orientations. The related elastic anisotropy can be assessed using shear wave birefringence measurements in which the ultrasonic propagation characteristics of a shear wave can be altered simply by changing its polarization state. The advantage of this approach over others is that the volume of material being studied is constant (fixing localized sample homogeneity) and only those microstructural elements that result in elastic anisotropy contribute to variation in the measurement. Beyond effective medium approaches, techniques for extracting microstructural information in materials that display a significant degree of ultrasonic scattering will be pursued. In most ultrasonics measurements, scattering of high frequency ultrasonic energy contributes to the background noise and is not investigated since interpretation cannot be carried out using simple time-of-flight analysis techniques. The scattered field can be recorded but can appear to simply be part of the background noise of the measurement system. Information related to the scattered field can be partially recovered using correlation techniques and can be used to perform microstructural characterization. Cross-correlation of recorded signals produces a null result if only random noise is recorded; however, if these signals are related through scattering from fixed locations in the sample, then signal related to the scattering processes experienced by the ultrasound will be recovered. Ultrasonic correlation should allow high frequency information contained in the scattered field to be recovered. We will assess the applicability of this approach to ultrasonic characterization of graphite. The importance of this overall investigation is that it will allow direct identification of different types of microstructural defects within the bulk of graphite bodies and will allow for monitoring of defect density changes brought about by thermal cycling and/or radiation-induced damage. The ability to nondestructively assess the microstructural state of nuclear-grade graphites is critical to qualifying these materials for current and future nuclear reactors. This type of examination is needed to qualify graphite in its as-produced state before value-added processing occurs to make components, to assess graphite components before they are assembled into systems for operational use and to evaluate in-service components to assure reactor integrity.