Rapid, Non-Destructive Detection of Microstructural Degradation in Light Water Reactor Structural Materials using Transient Grating Spectroscopy

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Critical components for light water reactors (LWRs) evolve over decades, losing ductility and toughness due to thermal and irradiation aging. Destructive techniques to monitor their health may not always be applicable in the field, thus non-destructive evaluation (NDE) methods are sought that can quickly and precisely identify the state of major LWR components such as core barrels, steam generator tubes, or primary coolant pipes. Here we demonstrate the use of gigahertz, non-contact ultrasonics to monitor and evaluate the health of cast austenitic stainless steels (CASS) and Alloy 690. We do so via changes in their surface acoustic wave (SAW) characteristics using transient grating spectroscopy (TGS). For the case of CASS, thermal aging is shown to induce SAW peak splitting, correlated strongly with aging time-at-temperature and Charpy impact energy, which are associated with increased hardness, decreased toughness, and lower ductility. This degradation in properties is associated with spinodal decomposition of delta ferrite network surrounding austenite grains. For the case of Alloy 690, decreased acoustic wave energy dissipation correlates with increased aging time-at-temperature following solution-annealing, water-quenching, and thermal treatment for seventeen hours at 700C. The degradation modes underlying these results are validated via microstructural analyses, nanoindentation measurements and molecular dynamics (MD) simulations. Together, these cases motivate looking at gigahertz ultrasonics as NDE techniques to indirectly detect other LWR material degradation modes, such as reactor pressure vessel (RPV) embrittlement. This would allow for the greater use of NDE techniques to enable confident monitoring of LWR structural material health to 80 years and beyond.