Atom Probe Tomography Provides Clues to Irradiation-Assisted Stress Corrosion Cracking

EPRI is gaining greater understanding of microstructural behavior through atom probe tomography – information that will aid the identification and management of materials susceptible to irradiation-assisted stress corrosion cracking.

Atom probe tomography (APT) is revealing details at the microstructure level that will enable the development of better models for assessing the susceptibility of BWR and PWR internals to irradiation-assisted stress corrosion cracking (IASCC). Such understanding, in turn, will lead to improved management and mitigation strategies, contributing to greater safety and higher equipment reliability, and potentially avoiding or reducing the billions of dollars in costs incurred by the nuclear power industry over the past 30 years to address the related phenomena of environmentally assisted cracking.

Neutron irradiation over time (or fluence, measured as displacements per atom) causes damage to vessel internal materials, predominantly stainless steels, that makes them more susceptible to IASCC. In addition, variations in IASCC susceptibility among heats of nominally the same alloy, at comparable fluence, are equally significant. Because the microstructural contributions to heat-to-heat variations are not well understood, bounding curves have been used to guide life assessment evaluations.

By their nature, bounding curves give disproportionate weight to materials with the highest susceptibilities; in applying the methodology, all materials are assumed to have the susceptibility defined by the bounding curve. As plants age, therefore, life assessment evaluations are expected to become more limiting. In particular, the current bounding curve correlates IASCC susceptibility with just one parameter: fluence. This is analogous to a doctor making an important prognosis based only on the patient's age, without taking into account other important physical measurements. Like the doctor, the nuclear power industry should use additional measurement-derived parameters to identify individual materials or components at higher risk.

For the last several years, EPRI has been using APT to reveal details of changes at the grain boundary and in the grain interior that earlier transmission electron microscopy (TEM) studies could not discern. The accompanying APT image shows silicon and aluminum-enriched clusters in the grain interior of a 304L stainless steel retrieved from a control-rod blade handle of an operating BWR that were not detected by TEM. These clusters could influence the deformation behavior, IASCC response, and fracture toughness of stainless steels.

At the grain boundary of the 304L stainless steel sample, APT revealed segregation of trace elements that TEM could not discern, but which may contribute to IASCC. For example, segregation of boron was observed, and B^{10}, which constitutes 20% of boron, will transmute under light water reactor irradiation to yield two daughter products: helium and Li^{7}. High levels of helium in the vicinity of the grain boundary are known to negatively affect welding of irradiated materials, and lower levels may exacerbate IASCC.

The evolution of clusters in the grain interior and the evolution of radiation-induced segregation at the grain boundary can follow different trajectories depending on variations in alloy composition, fluence,

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and metallurgical condition (annealed vs. cold-worked). Microstructural observations obtained with APT, in conjunction with those obtained by TEM, will enable the development of better models and indices to characterize IASCC susceptibility and lead to improved life assessment strategies for reactor internal components.

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