Quantifying Radiation Embrittlement in Structural Materials

Steven J. Zinkle[1,2]

[1]*University of Tennessee, Knoxville, TN 37996, USA*

[2]*Oak Ridge National Laboratory, Oak Ridge, TN 37831 USA*

It has been recognized for many decades that neutron irradiation can degrade the mechanical properties of structural alloys. However, different measures of ductility and embrittlement have been used in many different research studies, which can lead to confusion regarding quantitative comparison of ductility and embrittlement. In particular, the term "radiation embrittlement" that was initially introduced in the 1950s to describe the effect of neutron irradiation on materials that were sensitive to embrittlement (primarily body centered cubic metals and alloys) was subsequently broadly used since the 1960s to describe radiation induced ductility reductions; this is inappropriate terminology for many irradiated materials.

At low exposure temperatures (typically <0.4 $T_M$, where $T_M$ is the absolute melting temperature), radiation-induced defect clusters introduce significant hardening and concomitant reduction in tensile elongation. In particular, the uniform elongations of many metals and alloys decrease to <1% after irradiation doses ~0.1 to 1 dpa. However, the reduction in area, which is another well-established measure of ductility, typically remains very high (>90%). Fracture toughness, which is an accurate quantitative metric for embrittlement, tends to be only slightly degraded in irradiated face centered cubic and hexagonal close packed metals and alloys even when the tensile uniform elongation drops below 1%. Conversely, the fracture toughness of body centered cubic (BCC) metals and alloys can be dramatically reduced after low dose irradiation due to pronounced matrix hardening. In some cases, dangerously low fracture toughness is produced in irradiated BCC metals and alloys even when the tensile elongations are acceptably high.

At high irradiation temperatures, neutron-induced helium transmutations can lead to pronounced reductions in tensile elongation and transition to intergranular fracture (high temperature helium embrittlement). In general, postirradiation tensile testing dramatically overpredicts the magnitude of ductility loss compared to design-relevant in-reactor creep testing (particularly if relatively rapid strain rate tensile testing is used).

This presentation will compare and contrast commonly used measures of ductility and embrittlement. Recommendations for terminology to describe low-temperature ductility loss and fracture toughness embrittlement along with high temperature helium embrittlement will be proposed. Standard methods for quantifying ductility and embrittlement in irradiated structural materials will be summarized.