Effect of neutron irradiation on microstructure and mechanical properties of nanocrystalline nickel

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ABSTRACT:

Structural materials for the next generation nuclear reactor designs are expected to serve in more severe operating conditions than the current light water reactor designs. During irradiation, point, line, areal and volume defects are produced as a result of displacement cascades. At the macroscopic scale, the well-known deterioration of mechanical, thermal and physical properties of materials in radiation environments is attributed to the accumulation of radiation induced defects that leads to the formation of microscopic scale defect structures such as dislocations, loops and voids. Hence, the ability of a material to eliminate irradiation-induced point defects determines its radiation tolerance. Thus, identifying or designing materials with a tailored response that can sustain high amounts of radiation damage while maintaining their mechanical properties is a grand challenge in materials research.

One method to suppress accumulation of radiation induced defects is by annihilating them at interfaces such as grain boundaries. It has been shown that a large amount of grain boundary area will help to prevent accumulation of defects that can adversely affect mechanical properties. Nanocrystalline (NC) materials are polycrystals with a grain size <100 nm characterized by a large volume fraction of interfaces and triple junctions. Because grain boundaries act as sinks for irradiation-induced point defects, it was hypothesized that NC materials would possess enhanced radiation resistance compared to conventional micrograined materials. This is based on the premise that both the thermal stability and mechanical integrity of NC materials will be maintained under irradiation. The miniscule grain size of NC materials provides an excess of short diffusion paths for irradiation-induced point defects to migrate and annihilate at grain boundaries.

Even though NC materials present an unprecedented potential, scientific knowledge related to the effect of neutron irradiation is still scarce. In order to reach a firm conclusion on the potential of NC materials for nuclear reactor applications, extensive study of model metals with different stacking fault energy (SFE) is required to elucidate their behavior in radiation environments. As a part of an NSUF Irradiation Experiment project funded at NC State University, conventional and nanograined Cu, ECAP steel and Ni were irradiated in ATR (1 and 2 dpa). The selection of these materials was based on the motivation to investigate the effect of crystal structure (FCC vs BCC) as well as stacking fault energy (Cu vs Ni). Among these 3 materials, work was completed on Cu and ECAP steel which clearly revealed the influence of ultra-fine grain size on radiation hardening as well as microstructures while irradiated conventional and nanograined Ni samples were not tested in detail. This study is proposed to investigate the changes in mechanical properties and microstructures of irradiated Ni with particular attention to examine whether nanograined Ni is relatively more radiation resistant compared to conventional grained Ni. Some key questions that will be answered are: (a) What is the effect of neutron irradiation on the grain size; (b) What is the effect of higher SFE?; (c) What is the number density and mean size of stacking fault tetrahedra?; (d) Does nanocrystalline nickel show significant reduction of defect clusters, when compared with conventional Ni and NC Cu?