Elemental Effects on Radiation Damage in Tempered Martensitic Steels Irradiated to High Doses at Fast Reactor Relevant Temperatures

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ABSTRACT:

The primary aim of this NSUF Access-Only proposal is to ***quantify*** the connection between microstructure features and post-irradiation mechanical properties of tempered martensitic (TM) steels using previously neutron irradiated specimens to aid in the development of improved alloys. This will be accomplished via a comprehensive barrier hardening framework whereby grain size, dislocation density, precipitate populations, and solution strengthening contributions will be measured and used in the model. These information will provide guidance in optimizing the composition of this class of steel.

The secondary aim of this NSUF Access-Only proposal is to investigate whether neutron irradiation affects the rate of carbon loss from TM steels in contact with liquid sodium. This process, known as carburization and decarburization, happens with TM steels in contact with sodium under purely thermal conditions. Loss of carbon occurs when in contact with high purity sodium, causing grain boundary carbide dissolution and grain size coarsening. It becomes problematic for thin-walled structures at temperatures above 650°C.

These two goals are interconnected because there is evidence that under thermal conditions, higher chromium TM steels are more resistant to carbon loss. However, higher chromium steels may also be more prone to having poor toughness after irradiation at lower temperatures. Thus, there is a desire to more clearly identify what microstructural features most strongly affect toughness and decarburization as a function of TM steel composition.

PNNL has access to several heats of TM steels irradiated in the Fast Flux Test Facility to doses up to 110 dpa and temperatures between 370 and 500°C with compositional variations in carbon, silicon, manganese, nickel, vanadium, chromium and molybdenum which all play a role in microstructure evolution during alloy fabrication and irradiation. Tensile properties along with quantitative measurements of microstructure features including grain size, precipitate size and number density, dislocation density, matrix composition, and grain texture will be obtained.

These data will be used by the DOE-NE Advanced Fuel Cycle Program as input to develop TM steels with optimized compositions for their advanced sodium reactor concept. There are two important fringe benefits to this work. First is that data will be used to refine barrier hardening models for TM steels, in particular, to better define alpha coefficients for extended defects and strengthening coefficients for matrix solutes for this class of material. The second fringe benefit of this work will be an in-depth assessment of the effects of neutron irradiation and sodium contact on GB carbide dissolution and grain growth behavior. This will aid in ranking the severity of this issue relative to other degradation phenomenon as well as provide insight on the dependence of this phenomenon on alloy composition.

All sodium cooled reactor concepts will benefit from this work. This includes DOE-NE programs and commercial sodium-cooled reactor concepts such at the Terrapower Natrium reactor concept. Advanced light water and potentially molten salt reactor concepts will also benefit.