Development of Advanced High-Cr Ferritic/Martensitic Steels

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Program: Fuel Cycle – 2.2 Extreme Performance Metal Alloy Cladding for Fast Reactors

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ABSTRACT:

To meet the requirements of next-generation nuclear reactors, materials must be developed that can withstand irradiation doses up to 600 displacements per atom (dpa). Ferritic/Martensitic (F/M) steels are a promising class of iron (Fe) based alloys, containing chromium (Cr) levels of 9-12 % by weight, that have huge potential to meet the ambitious requirements for next-generation reactors. F/M alloy HT-9 has had great success in reactor applications because it offers excellent resistance to irradiation hardening, swelling, and embrittlement at reactor service temperatures (400-600°C), and also has outstanding thermal conductivity and corrosion resistance. The primary impediment for widespread industrial implementation of HT-9 is the development of embrittlement at slightly lower temperatures (300-400°C) that occur at the inlet regions of reactors.

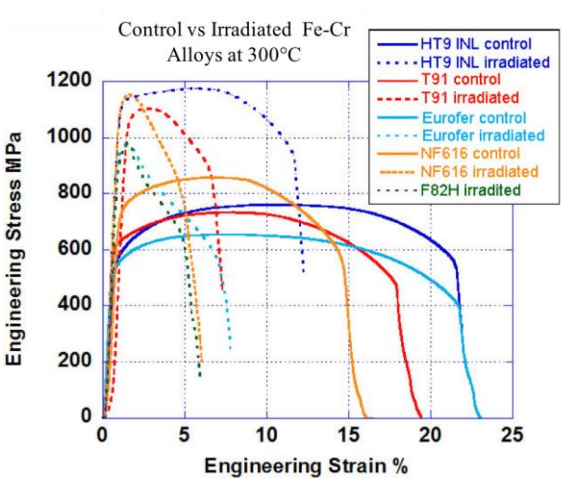

Figure 1. Low-interstitial containing HT-9 showed the least reduction in ductility after irradiation at 300°C. [10]

Our team has recently found that decreasing the nitrogen content in HT-9 alloy heats (nitrogen levels can vary substantially with changes in manufacturing), the embrittlement that occurs at lower temperatures (i.e., 300°C) is greatly reduced, as shown in Fig. 1. In other words, the amount of engineering strain that results in fracture (total ductility) changes from roughly 22% before irradiation to 12% after irradiation for HT-9, whereas the other F/M alloys listed, with higher nitrogen content, have substantially greater reduction in ductility for the same test conditions. The “free” nitrogen present in an alloy can be effectively eliminated by designing the material to produce small, nitrogen-containing particles (precipitates) that “tie-up” nitrogen and minimize the effect on mechanical performance.

Thus, our project is a systematic study to develop an understanding of precipitate design and processing changes in the production of F/M steels to suppress void swelling and improve low temperature ductility loss. The objective of this study is to use a science-based approach, combining thermodynamic and kinetic modeling with experiments, to guide alloy design and measure success with performance evaluations (both before and after irradiation) with the goals of (1) substantially reducing low temperature (300-400°C) embrittlement by removing “free” nitrogen and (2) simultaneously create fine, stable particle dispersions within the material that can be used to improve strength, ductility, and irradiation resistance.