PRECIPITATION IN NEUTRON IRRADIATED Fe-Cu-Mn-Ni MODEL ALLOYS

M.K. Miller, K.F. Russell, G.R. Odette* and B. D. Wirth+
Metals and Ceramics Division, Oak Ridge National Laboratory,
Oak Ridge, TN 37831-6136, USA
*Department of Chemical Engineering, University of California - Santa Barbara,
Santa Barbara, CA 93106, USA
+Nuclear Engineering Department, University of California, Berkeley, CA 94720, USA.

The microstructures of a systematic series of Fe-Cu-Ni-Mn model alloys have been characterized by atom probe tomography (APT) and small angle neutron scattering (SANS). The primary aims of this study were to determine whether any precipitation occurs in low (0.05%) and copper-free alloys during neutron irradiation and to determine the influence of nickel.

The OV series of alloys contained 0, 0.05 or 0.1% Cu, 0.8 or 1.6% Ni and 1.6% Mn. An Fe-0.05% Cu, 1.6% Mn, 1.6% Ni, 0.025% P, 0.5% Si was also characterized to investigate the effects of phosphorus and silicon. These model alloys were neutron irradiated to a fluence of ~1.3×10^{23} n m^{-2} (E > 1 MeV) at a temperature of 290°C. The microstructures of these model alloys were characterized in the Oak Ridge National Laboratory's local electrode atom probe and by small angle neutron scattering at the National Institute for Standards and Technology Center for Neutron Research.

After neutron irradiation, the hardness of the alloy was found to increase with the copper content for the same nickel and manganese levels. The hardness increased with nickel content at the same manganese level for both low (0.05%) and high (0.1%) copper alloys. The hardness was higher in both high (0.1%) copper alloys. The hardness also increased with silicon plus phosphorus additions. SANS indicated that small features were present in all alloys. The radius <R> of these features was between 0.5 and 1 nm, and increased with Cu and Ni levels and decreased with the silicon plus phosphorus additions. The number density was between 0.5 and 1.8×10^{24} m^{-3}, and increased with the silicon plus phosphorus additions. The M/N was between 0.4 and 1. APT also detected solute-enriched precipitates in all alloys, including those with no and very low copper. Some precipitates were enriched in Ni and Mn and some were enriched in Cu, Ni and Mn. In the silicon plus phosphorus alloy, the precipitates were enriched in Cu, Ni, Mn, Si and P. Copper-enriched precipitates were observed in the 0.05% Cu alloys indicating that 0.05% Cu is above the solubility limit under these neutron irradiation conditions. The Cu, Ni and Mn atom distributions were not located at the same center-of-mass as has been predicted by Monte Carlo simulations.

Research at the Oak Ridge National Laboratory SHaRE User Center was sponsored by the Division of Materials Sciences and Engineering, U.S. Department of Energy, under contract DE-AC05-00OR22725 with UT-Battelle, LLC and by the Office of Nuclear Regulatory Research, U. S. Nuclear Regulatory Commission under inter-agency agreement DOE 1886-N695-3W with the U. S. Department of Energy. Research at UCSB was sponsored by the U. S. Nuclear Regulatory Commission NRC-04-01-064.