Effects of Helium on the Mechanical Properties and Microstructure of Niobium

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Mechanical property specimens of niobium (Cb) were doped with helium by the tritium trick to concentrations as high as 500 appm. The tritium decays by the reaction $^3\text{H} \rightarrow ^3\text{He} + \beta^-$ at a rate that produces about 7 appm per day in the Niobium microstructure. Tensile properties were measured from room temperature to 800°C, and creep properties from 700 to 1000°C at stresses from 45 to 75 MPa. Transmission electron microscopy was used to study the microstructure of the helium doped specimens, and the observations were correlated with the mechanical property results. The results of this investigation showed that niobium has a high tolerance to helium trapped in the microstructure. The tensile and creep strengths of niobium increased as helium concentration increased. The ductility decreased significantly as the helium concentration increased, but niobium retained substantial ductility even at high helium concentrations of 500 appm.

All proposed D-T fusion power reactors will generate high fluxes of 14 MeV neutrons. Bombardment of metallic, insulator, or superconductor components in the reactor by these energetic neutrons, in most cases, will cause material degradation and will increasingly limit fusion reactor performance with increasing neutron fluence. Fission neutron irradiation is known to change the mechanical properties of materials, usually reducing component lifetime and adversely affecting reactor economics. For this reason, understanding and predicting the effect of fusion neutron irradiation on the properties of potential reactor materials is of great importance.

High energy ($E \approx 14$ MeV) neutron radiation from fusion reactors will cause enhanced damage to reactor materials. The displacement damage per incident 14 MeV neutron is greater, and cross-sections for $(n,\alpha)$ reactions also are higher for fusion neutron irradiation than for fission neutron irradiation. Mechanical properties of reactor materials are changed by relatively small concentrations of helium. Because of high $(n,\alpha)$ cross-sections, large concentrations of helium will be produced in fusion reactor materials irradiated by 14 MeV neutrons in a relatively short time span. A concentration of about 25 appm helium will be produced internally in niobium by a fusion neutron flux of $\sim 10^{25}$ neutrons m$^{-2}$s$^{-1}$ with one year’s exposure. Helium atoms produced in a host matrix having low helium solubility are thermodynamically unstable and have a high driving force to coalesce in the microstructure at various defects. Thus, helium atoms tend to migrate to dislocations, precipitates, grain boundaries, impurity particles, and microcracks where they coalesce to form bubbles. These helium induced defects generally cause embrittlement.

One method for introducing helium into the microstructure of metals and alloys is by the radioactive decay of dissolved tritium to helium. This process is commonly called the tritium trick. In this investigation we studied the effect of helium on tensile and creep properties of niobium doped with helium by the tritium trick to concentrations as high as 500 appm. The microstructure of specimens containing helium was characterized by transmission electron microscopy and was correlated with the mechanical properties.

EXPERIMENTAL PROCEDURE

The niobium used in this study was ordered in wrought form. Metallic impurities (wt ppm) were A1-70, Ta-230, W-60, Zr-150, and others <50. Nonmetallic impurities (wt ppm) were C < 30, N-30, and O < 50. The niobium was cross-rolled to 1.6 mm thickness with a 50 pct reduction on the final pass. Before being charged with helium, niobium specimens were given a 2 h anneal at 1200°C. Pressures in the furnace chamber were less than 1.3 μPa in all annealing runs. This heat treatment produced a microstructure with uniform, equiaxed grains. The average grain size was about 50 μm.

Helium was charged into the niobium by first dissolving about 5 at. pct tritium in the metal at 400°C. The specimens were held at constant temperature while the tritium decayed to helium by the reaction $^3\text{H} \rightarrow ^3\text{He} + \beta^-$ (tritium trick). When the desired level of helium had been introduced into the metal, most of the more mobile tritium was removed by vacuum extraction at the same temperature used for charging. Final tritium concentrations were less than 10 appm after vacuum extraction. Carbon, oxygen, and nitrogen levels were not affected by the charging process. Final helium concentrations were verified by precision mass spectrometry.

Short-term tensile tests were done in a stainless steel clam-shell furnace mounted on an Instron Universal testing machine. All flange seals were Viton, and a 6 in. diffusion pump coupled with a liquid nitrogen cold trap provided pressures less than 13 μPa for the range of 10 s.
RESULTS AND DISCUSSION

Tensile Tests

The effects of helium on the strength and ductility of niobium tensile tested at 23 and 800°C are shown in Figs. 1 and 2. The 0.2 pct offset yield stress at 23°C was insensitive to helium concentration, and the...