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Mechanical Properties Testing, Characterization and Modeling of Proton-irradiated Ti-base Alloys and Beryllium

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Titanium-base alloys and beryllium are currently used as beam windows in multiple accelerator facilities due to their limited interaction with the beam, high strength, and radiation damage tolerance. The Tokai-to-Kamioka neutrino beamline at J-PARC uses the two-phase (alpha+beta) alloy Ti-6Al-4V as the material for both its primary beam window and target containment beam windows. The hadron facility at J-PARC and the Long Baseline Neutrino Facility at Fermilab are both planning to use beryllium windows for the primary beam and/or decay pipe. Planned upgrades to beam power above 1.3 MW would push these materials beyond their current operational experience. Relatively little is known about how Ti-base alloys or beryllium would respond to higher beam power and dose (dpa).

Irradiation studies on alpha-Ti alloys and alpha+beta Ti alloys such as Ti-6Al-4V have been conducted in fission reactors and low energy ion accelerators, but high energy proton irradiation data are limited. Ion irradiations are useful to observe microstructural evolution and micro-mechanical property changes to very high dose, but they are not useful for determining bulk material properties due to limited depth of ion penetration. Neutron irradiation data show effects such as hardening, increased strength, loss of ductility, and swelling. There are suggestions that there may be fundamental differences in irradiation response between alpha-Ti alloys, alpha+beta Ti alloys and the less-investigated metastable beta-Ti alloys. However, effects from neutron irradiation can be quite different than those from high energy protons where damage rate and gas production are much higher.

Beryllium has been used in research and test reactors and there is good understanding of its performance during low-temperature fission neutron irradiation. However, there is little data available for beryllium from elevated temperature high-energy proton irradiation. One phenomenon clearly observed in fission reactor irradiation is swelling caused by production of helium and tritium. The gas production rates in high-power proton accelerators can be up to ten times higher than in fission reactors. Understanding how helium and hydrogen behave in beryllium at prototypic beam window conditions is important, as is understanding the effects of gas production on mechanical properties.

In 2018 an international team of researchers from the Radiation Damage In Accelerator Target Environments (RaDIATE) Collaboration, completed irradiation of specimens by 181 MeV protons in the Brookhaven Linac Isotope Producer (BLIP) facility at Brookhaven National Laboratory. Experimental data for a variety of near-alpha, alpha+beta and near-beta Ti-base alloys and two varieties of beryllium included in the BLIP irradiation will be described. For the Ti-base alloys, the data include elastic modulus and tensile results along with complementary fractography, scanning electron microscopy with electron backscatter diffraction and transmission electron microscopy for crystallography, and atomic force microscopy for nanohardness. The presentation also will provide a summary of molecular dynamics modeling of high-energy proton irradiation damage in Ti at the atomic scale to understand fundamental radiation damage mechanisms. For the beryllium samples, elastic modulus, tensile and four-point bend data will be discussed along with complementary fractography and transmission electron microscopy to evaluate the concentration and size of bubbles from gas production.

Themes for the contribution

2 Radiation damage in target material and related simulations:

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