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SPALLATION SOURCE MATERIALS TEST PROGRAM

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Abstract

A spallation source materials program has been developed to irradiate and test candidate materials (Inconel 718, 316L and 304L stainless steel, modified 9Cr-1Mo(T91), Al6061-T6, Al5052-O) for use in the Accelerator Production of Tritium (APT) target and blanket in prototypic proton and neutron fluxes at prototypic temperatures. The study uses the 800 MeV, 1mA proton accelerator at the Los Alamos Neutron Science Center (LANSCE) which produces a Gaussian beam with 2 sigma = 3 cm. The experimental set-up contains prototypic modules of the tungsten neutron source and the lead/aluminum blanket with mechanical testing specimens of candidate APT materials placed in specific locations in the irradiation area. These specimens have been irradiated for greater than 3600 hours with a maximum proton fluence of 4-5 x 10^{21} p/cm^2 in the center of the proton beam. Specimens will yield some of the first data on the effect of proton irradiation to high dose on the materials' properties from tensile tests, 3 pt. bend tests, fracture toughness tests, pressurized tubes, U-bend stress corrosion cracking specimens, corrosion measurements and microstructural characterization of transmission electron microscopy specimens.

Introduction

Concept

The accelerator production of tritium (APT) program proposes to use a 1.7 GeV, 100 mA proton accelerator to bombard a tungsten target which produces neutrons to be captured by He^3 or Li^6 to form tritium. A cross-section of the APT target and blanket region is shown in Fig. 1. The materials used in this region will be subjected to several different particle radiation environments; high energy protons (1-2 GeV), high energy protons and neutrons, high energy neutrons, and low energy neutrons, depending on the position in the target and blanket. The candidate materials for the target/blanket area are: Inconel 718 or 316L stainless steel for the window; tungsten, tungsten clad with Inconel 718 or 316L stainless steel, or tantalum for the neutron source; 316L stainless steel for containing the tungsten rods and for much of the target and blanket structure; lead as a neutron multiplier in the blanket area; and Al6061-T6 or Al5052-O to hold the pressurized He^3 gas. To build this structure one must know how the properties of these materials will change in a spallation source radiation environment. Therefore, a spallation source materials test program has been developed which uses the 800 MeV, 1 mA proton accelerator at LANSCE (Los Alamos Neutron Science Center) to irradiate test specimens of materials and prototypic target and blanket assemblies in similar proton and neutron spectra to those expected in the APT target and blanket conceptual design.

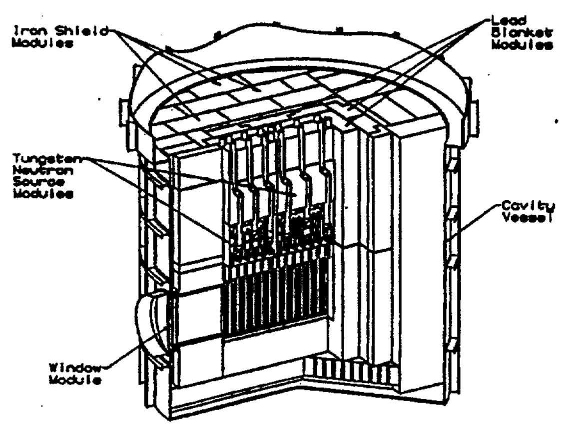

Figure 1: Schematic cross section of an APT target and blanket assembly. one half of the blanket assembly has been removed for clarity.

Insert Set-up

A detailed description of the set-up of inserts and water systems developed for this study can be found in reference [1]. In summary, the irradiation set-up (see Figure 2) consists of five inserts in the proton beam (proton inserts labeled 17A, 18A, 18B, 18C and 17B) and three inserts located next to the beam (neutron inserts labeled 9A, 9B, 9C). The number in the labeling refers to the type of the insert. The inserts contain materials placed in proton and neutron fluxes similar to those expected in the APT target and blanket. Thus, insert 17A contains specimens of candidate window materials and target containment materials such as Inconel 718, 316L stainless steel, 304L stainless steel and modified 9Cr-1Mo. Insert 18A holds the neutron source which consists of clad tungsten rods held in 304L stainless steel tubes. Insert 18B holds candidate APT materials above the beam and surrounding the beam experiencing a high neutron flux produced by the tungsten source on insert 18A. It also holds prototypic APT lead and aluminum blanket assemblies. Insert 18C holds a similar set of specimens to those in insert 17A in the proton and neutron flux present after the beam passes through the tungsten neutron source. Insert 17B holds corrosion test specimens of candidate APT materials to determine the in-beam and out-of-beam corrosion rate using a controlled water system for cooling. Inserts 9A, 9B and 9C hold lead and aluminum blanket assemblies and specimens of APT candidate materials similar to those on Insert 18B but in a predominant neutron flux. All specimens and prototypic APT assemblies are instrumented with thermocouples to measure their irradiation temperature and activity foils to determine the achieved fluence.

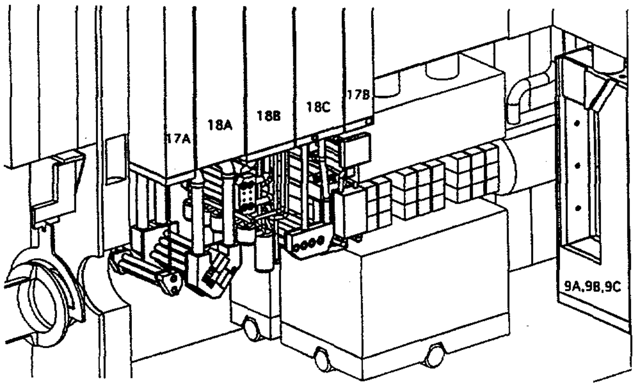

Figure 2. Close-up of the arrangement of capsules used to expose samples and prototype components to a spallation source radiation environment.

The following paragraphs discuss the history and schedule of the spallation source materials study and data which will be obtained from it.

Irradiation History

The spallation source materials test program began in November 1995 when the inserts were designed, tested and manufactured using detailed physics and thermohydraulic calculations to predict the temperatures and proton and neutron fluences on specimens placed in specific locations with respect to the proton beam. All inserts were carefully loaded into the irradiation area by August 1996. The accelerator was successfully turned on and tuned to a 800 MeV 1 mA beam in the beginning of September 1996 and ran until the beginning of November 1996. At this time a high concentration of tungsten corrosion products was observed in water samples taken from the closed loop water system on insert 18A suggesting an unacceptably high in-beam tungsten corrosion rate. This insert used bare tungsten rods as a neutron source. Thus, it was decided to replace insert 18A with a new insert using tungsten clad with 304L stainless steel during a four month downtime for the accelerator. The bottom of the old insert 18A holding bare tungsten rods was removed and analyzed in a hot cell and confirmed the high corrosion rate suggested by the high concentration of tungsten corrosion products found in the water samples. During the same time, a new corrosion insert with its own closed loop water system was manufactured and placed on insert 17B.

All inserts were in place and ready for the proton beam by the middle of March 1997. The beam was tuned to 800 MeV, 1mA by the end of March 1997 and ran until the end of July 1997 totaling 3600 hours for all inserts except insert 17B, the corrosion insert and Insert 18A, the clad tungsten insert which were not in place for the first 2 month irradiation period. By this time, the specimens in the center of the 800 MeV, 1mA proton beam having a Gaussian profile with two sigma of approximately 3 cm received an approximate fluence of $4\text{-}5\times10^{21}$ p/cm^2 at temperatures ranging from 150 to 200° C.

Future Plans

Starting in the middle of August 1997, inserts 18C, 17B, 18B, 9A, 9B and 9C will be removed from the facility, cut from the bottom of the inserts and shipped to the hot cells to carefully remove and categorize each specimen. Then, some specimens will stay at LANL to be tested and other specimens will be shipped to Pacific Northwest National Laboratory (PNNL), Oak Ridge National Laboratory (ORNL) and Brookhaven National Laboratory (BNL) to begin testing by January 1998. In the meantime, three new proton inserts will be designed, manufactured and installed to be ready for the next four month irradiation period starting in June 1998.

Materials Data

The mechanical and corrosion properties after proton and neutron irradiation of candidate APT materials will be determined in the course of this spallation source materials program. These materials are Inconel 718, 316L and

304L stainless steel, modified 9Cr-1Mo(T91), Al6061-T6 and Al5052-O. Microstructural changes from irradiation will also be observed in these materials as well as tungsten, tantalum and corrosion lead. The specimens chosen to measure the mechanical properties in the proton beam are small and thin to obtain a uniform fluence over the specimen at a constant temperature.

Tensile

The tensile properties will be measured after irradiation in the direct proton beam using small scale sheet tensile specimens described in reference [2] (dimensions are 16 mm long, 5 mm gauge length, gauge crossection=0.25 mm x 1.2 mm). A slightly larger specimen (25.4 mm long, 7.62 mm gauge length, gauge crossection=1.52 mmx 0.76 mm) called a SS-3 specimen [3] is being used to measure the properties of APT prototypic welds. To investigate specimen size effects, the tensile properties measured from these small scale specimens will be compared to the tensile properties measured from an ASTM subsize specimen following ASTM E 8M-93. To investigate the tensile properties using a 3 mm diameter disk, shear punch testing will also be performed on each material [4]. This specimen may prove to be an excellent specimen to use for surveillance testing during the APT plant life.

3 point bend

The properties of materials in 3 point bending will be measured using small-scale specimens, 2mm x 8mm x 0.25 mm, in the proton beam and compared to bend results from testing larger specimens, 38.1 mm 3.81 mm x 0.25 mm in the proton and neutron flux. These small scale specimens may also prove to be important specimens to use for surveillance testing during the APT plant life.

Fracture Toughness

The fracture toughness, J_{IC} will be measured using the unloading compliance method with subsize disk compact specimens (diameter = 12.5 mm) developed at ORNL[5]. Thin specimens (thickness=2mm) are used in the direct proton beam and thicker specimens (thickness=4 mm) are used in the proton and neutron flux.

Creep

Using 25.4 mm long, 4.57 mm diameter pressurized tubes, irradiation creep of Al6061-T6, Al5052-O, 304L and 316L will be measured after irradiation in a proton and neutron flux. This technique has also been used to study creep at the Oak Ridge Research Reactor [6]. Tubes were pressurized with He to fractions of the yield strength and their increase in diameter will be measured after irradiation to determine the creep which has occurred during irradiation.

Stress Corrosion Cracking

Stress corrosion cracking will be investigated in Inconel 718, mod 9Cr-1Mo, 316L and 304L in the proton beam using small scale U-bend specimens (thickness = 1 mm, radius = 2 mm) and in the proton and neutron flux using ASTM G30-90 standard U-bend specimens (thickness = 2.5 mm, radius = 5 mm).

Corrosion

The corrosion rate of tungsten, tantalum, 316L, 304L and mod 9Cr-1Mo will be measured in the proton beam using weight loss specimens in which the weight is accurately measured before and after irradiation. In addition, the corrosion rate of all candidate APT materials is being measured in irradiated water using a well characterized closed loop water system.

Microstructural Analysis

From 3 mm diameter disks, the change in microstructure after irradiation will be determined using transmission electron microscopy. These disks will also be used to determine the amount of irradiation swelling and gas production in the specimens.

Conclusions

APT candidate materials (Inconel 718, 316L and 304L stainless steel, modified 9Cr-1Mo(T91), Al6061-T6 and Al5052-O) have been irradiated for greater than 3600 hours with a 1 mA, 800 MeV proton accelerator (having a Gaussian beam with 2 sigma = 3cm) at LANSCE. A total fluence for the specimens in the center of the beam equals 4-5 x 10^{21} p/cm^2. Some of the first mechanical properties data after proton irradiation to high dose will be obtained from tensile, bend fracture toughness, pressurized tubes and stress corrosion cracking specimens and correlated with the microstructure.

Acknowledgments

This program required a large collaboration involving engineers from numerous groups at Los Alamos National Laboratory as well as a materials working group consisting of representatives from Pacific Northwest National Laboratory, Oak Ridge National Laboratory, Sandia Livermore National Laboratory, Lawrence Livermore National Laboratory, Savannah River Technology Center and Brookhaven National Laboratory. We are equally indebted to all participants.

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