PROGRESS IN CONSTRUCTION OF A V-4CR-4TI THERMAL CONVECTION LOOP AND TEST FACILITY—B. A. Pint, S. J. Pawel, and J. L. Moser (Oak Ridge National Laboratory)

OBJECTIVE

The objective of this project is to operate a flowing Li experiment to test the Li compatibility in a thermal gradient of V-4Cr-4Ti and a multi-layer electrically-insulating coating needed to reduce the magneto hydrodynamic (MHD) force in the first wall of a lithium cooled blanket. The experiment is planned to start in January of 2007 and run for 1,000h at 750°C.

SUMMARY

A vacuum chamber and ancillary equipment are being assembled for the experiment. A loop design has been formalized and V-4Cr-4Ti tubing has been received and examined prior to fabrication of the loop. Specimens and wire for the hot and cold leg have been fabricated. Specimens have been prepared for two layer MHD coatings at Lawrence Livermore National Laboratory.

PROGRESS AND STATUS

Introduction

A self-cooled lithium blanket concept is attractive for a fusion reactor because of lithium's tritium breeding capability and excellent heat transfer characteristics. Due to compatibility issues at >500°C, vanadium alloys [1] are the most likely structural materials for this concept. One of the critical issues for this, and any liquid-metal concept, is the need to reduce the pressure drop associated with the magneto hydrodynamic (MHD) force due to the high magnetic field in the reactor [2,3]. One solution to the MHD problem is to apply an electrically insulating coating to decouple the structural wall from the liquid metal [4]. The coating must be thin, durable and have a high electrical resistivity. It also must be almost crack-free to prevent shorting [5,6]. The current focus of the U.S. program on reducing the MHD pressure drop is on durable multi-layer coatings or a flow-channel insert [7,8]. Both of these solutions have been previously proposed [4,9,10]; however, little experimental verification has been conducted. Both concepts rely on excellent compatibility of a relatively thin V or V alloy layer to prevent Li from contacting and degrading the insulating ceramic layer. Initial capsule and in-situ testing of multi-layer coatings have shown promising results [11]. However, a flowing Li test with a temperature gradient is needed to validate the compatibility of such thin layers. A brief summary of the vanadium-lithium compatibility literature [12] showed a wide range of results with no systematic study of the effects or relative importance of alloying elements and Li impurities. Ideally, a monometallic loop with relatively high purity Li and V specimens is needed to clarify the range of results found for V alloys in Li and preparations for a flowing Li thermal convection loop experiment are currently underway. The current plan is to run the loop for 1000h with a maximum temperature of 750°C beginning in January 2007. The loop will be destructively evaluated after the test with characterization completed by the end of March 2007.

Results and Discussion

Experimental hardware. A vacuum of ~10^{-6} Pa is need to run a high temperature V-4Cr-4Ti loop to avoid excessive oxygen uptake, and subsequent embrittlement, by the vanadium alloy tubing during the experiment [13]. A vacuum chamber with control system has been delivered and installed and is undergoing initial test out at ORNL, Figure 1a. To reach the required vacuum, the entire chamber must be baked out requiring an insulating cover for the system, Figure 1b. The heating elements are located in the panel behind the chamber. The unit was tested to the specified vacuum at the manufacturer prior to

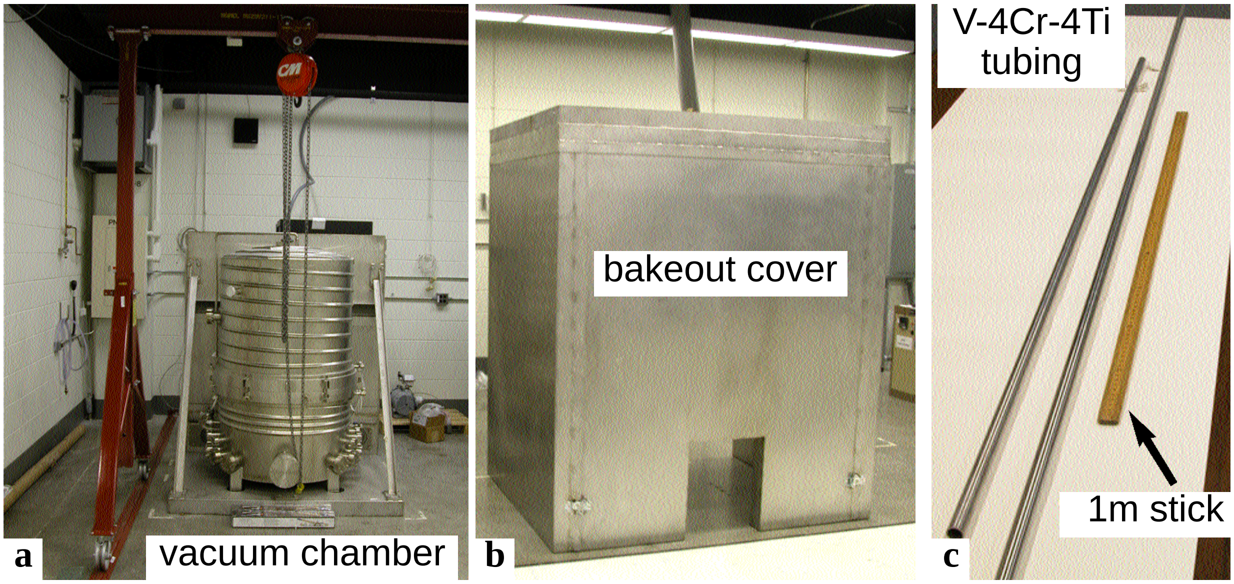

Figure 1. Photographs of (a) the vacuum chamber (base vacuum of <10-6Pa) and overhead crane, (b) the bakeout furnace and (c) the V-4Cr-4Ti tubing.

shipment. A crane also has been installed to move the cover and raise the top of the chamber to install the loop. Three Mo heaters have been ordered. Two will heat the hot leg of the loop and the third will heat the Li in the fill tank to begin the experiment.

Loop construction. A simple loop design will be used. It was developed for a recently cancelled program and based on early ORNL designs. To construct the loop, V-4Cr-4Ti tubing and sheet are needed. Approximately 4 m of V-4Cr-4Ti tubing (19mm OD, 1.6mm wall thickness) was procured and delivered in March 2006. To qualify the material, the tubing first was visually examined and metallography was performed to examine defects. Figure 2a shows a representative longitudinal section of the tubing. The grain size was uniform across most of the thickness and only near the surface was the grain size small

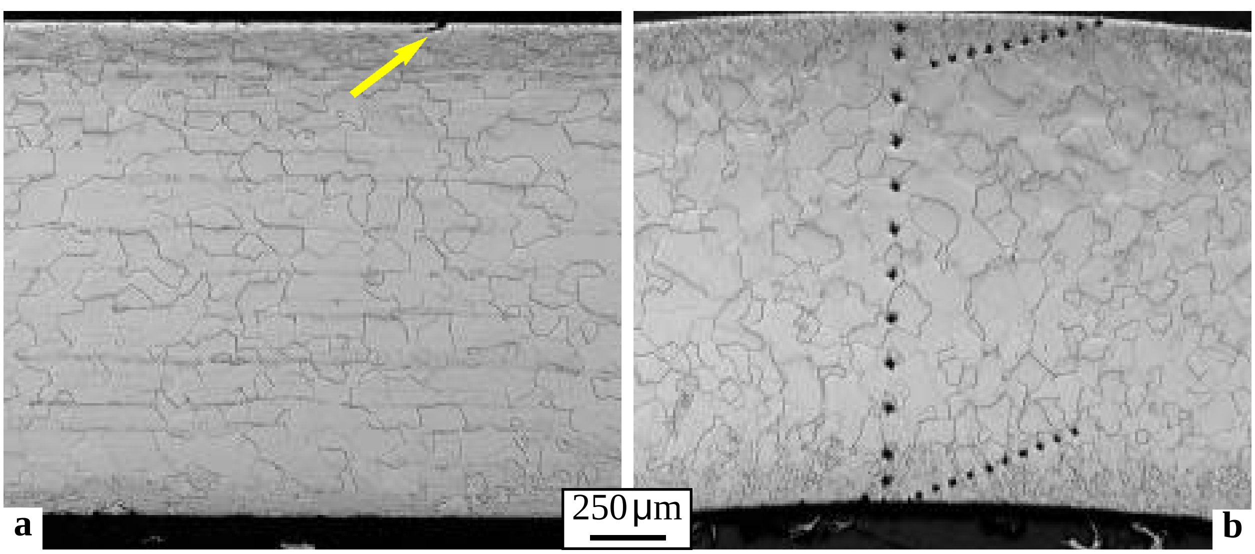

Figure 2. Light microscopy of the V-Cr-4Ti tubing (a) longitudinal section and (b) cross-section. A crack was observed in (a) and hardness tests are shown in (b). The etchant was $60H_2O-30HNO_3-10HF$.

and disturbed. There is some evidence of banding. A small crack is marked (arrow) on the outside surface. The effect of the structure gradient was measured by hardness testing. The hardness in the central, equiaxed grain portion is routinely H_V 148-152. Near cracks the hardness increases to H_V 165-172 while near both surfaces the hardness is typically H_V 132-138.

One of the worst sections from visual examination was sectioned and deeper cracks were observed with the deepest (~52% of wall thickness) shown in Figure 3a. Finer grains and possibly some inclusions surround this crack. A more nominal depth for the flaws was 15-20% of the wall thickness, e.g., Figure 3b. Most cracks were not perpendicular to the outer surface. At the higher magnification in Figure 3b, the transgranular crack propagated through the fine-grained layer that was more heavily etched, perhaps indicating more precipitates. Also, a ~5µm surface layer (arrow) can be seen that has not been identified. The layer almost bridges the crack. Cracking also was observed on the inner diameter with the deepest being 12% of wall thickness but most only 1-2%, Figure 3c. Some of the wider, shallow cracks suggest "grain dropping" and were visible to the naked eye when the tubing was cut open.

The room temperature ductility was assessed by flattening sections of tubing in a bench vise. Defects in each section were placed perpendicular to the platens to place maximum tensile stress on the defects. In each case, the flaw opened cleanly but there was no indication of propagation and the remaining section was fully ductile. To further assess the overall tubing quality, a helium pressure test (690kPa, 100psig) was performed on each of the three tubing sections. Swagelok fittings were placed on each end of the entire tube length along with a pressure gage. The pressure remained steady and unchanged for 24h for all three tubes. The tubes are expected to contain a much lower pressure (~100kPa) so the as-received material appears to be adequate for loop construction. The final characterization planned is to use the tubing to make a capsule and perform a 1000h 800°C Li capsule test to ensure that the tubing has compatibility similar to the prior V alloy capsule tests performed at ORNL [7,14].

Compatibility specimens. Specimens of V-4Cr-4Ti to be placed in the hot and cold legs of the loop have been fabricated, Figure 4. Tensile specimens (SS-3 type) will be used in order to determine post-test mechanical properties along with 0.75mm thick tab or spacer specimens that center the specimen chain in the tube, top of Figure 4. Also, 0.75mm diameter V-4Cr-4Ti wire has been made to connect the loop specimens. Ten, 1mm thick spacer specimens were sent for coating using electron-beam physical vapor

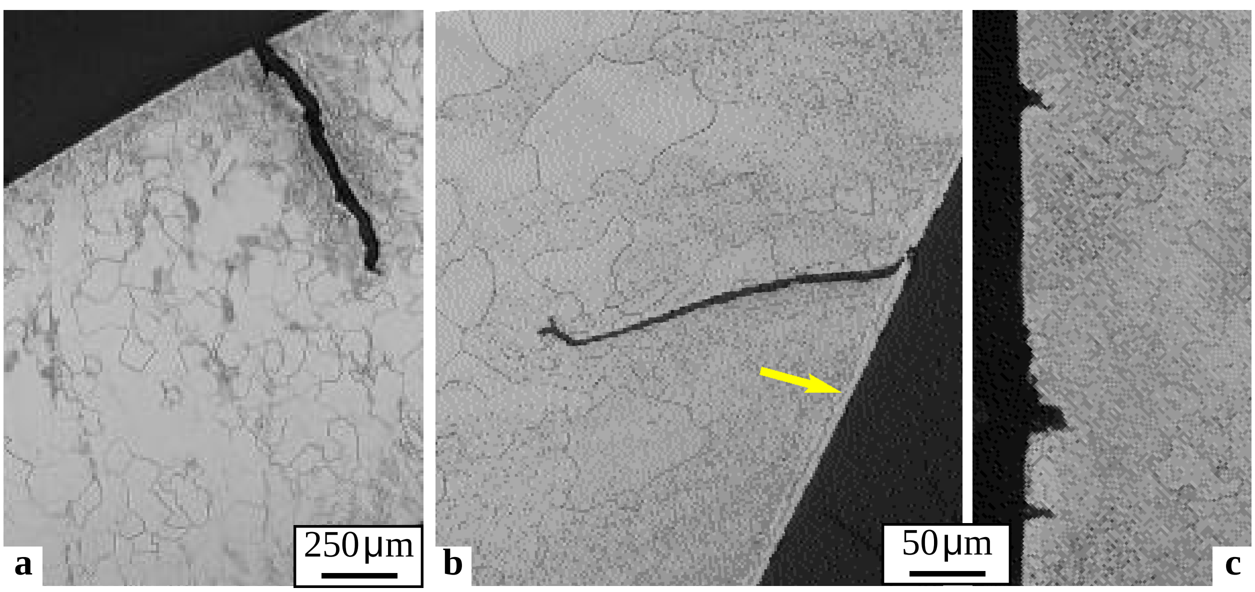

Figure 3. Light microscopy of cross-section of the V-Cr-4Ti tubing showing cracks on the (a,b) outer diameter and (c) inner diameter. Arrow in (b) marks unidentified outer layer.

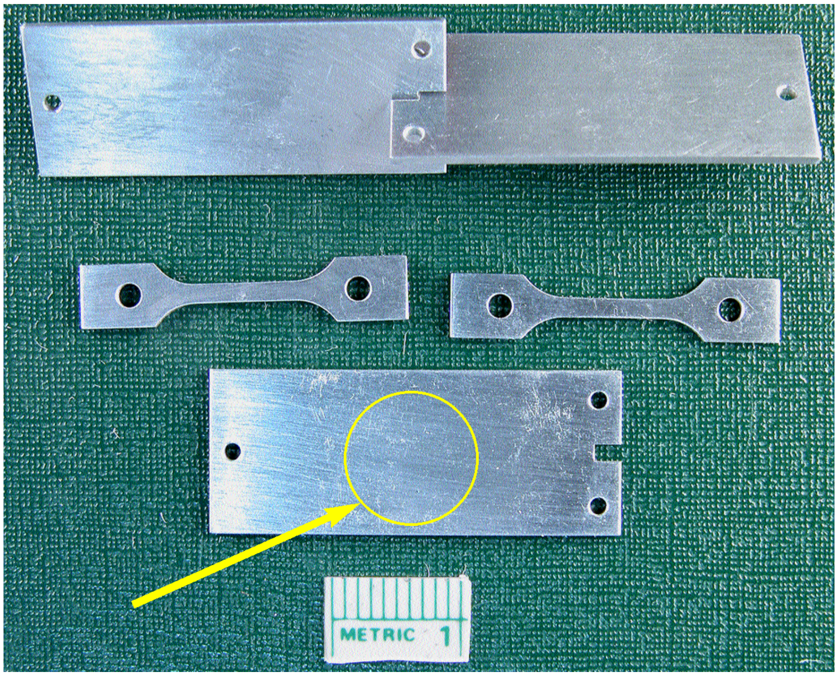

Figure 4. Photograph of examples of V-4Cr-4Ti tab and SS-3 tensile specimens prepared for the loop experiment. The circle (arrow) gives an indication of the PVD oxide (Y_2O_3 or Er_2O_3) coatings that will be applied to some specimens and then overcoated with 10µm of vanadium.

deposition (EB-PVD) at Lawrence Livermore National Laboratory (LLNL). Half will be coated with Er_2O_3 and half with Y_2O_3. The approximate size of the oxide coating is shown by the circle in Figure 4. All of the specimens will then be overcoated with a 10µm layer of vanadium layer. One of each type will be kept to measure the as-coated resistance. Coated specimens will be placed in both the hot and cold legs of the loop but more will be placed in the hot leg.

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