EVALUATION OF THERMAL CREEP OF V-4Cr-4Ti IN A LITHIUM ENVIRONMENT —
M. L. Grossbeck (Oak Ridge National Laboratory)

OBJECTIVE

The goal of this research is to evaluate the creep behavior of V-4Cr-4Ti under conditions where oxygen is not increased during the test. This will allow thermal creep to be separated from irradiation and helium effects in DHCE experiments and will aid in interpretation of the vacuum thermal creep experiments now being performed.

SUMMARY

Thermal creep in vanadium alloys can be measured by pressurized tubes. The tubes are pressurized with helium at a series of pressures to give the desired stresses in the tube wall. The diameter of the tubes is very precisely measured before and after high temperature exposure to determine creep deformation. A pair of high temperature furnaces and retorts have been fitted into an inert gas glove box system. Liquid lithium will be contained in the retorts which will contain the pressurized tubes of the vanadium alloy to be tested. The refractory metal retorts have been equipped with pressure sensors to determine to time of tube failure. This system will be used to determine time of failure and strain to failure as a function of stress.

INTRODUCTION

In order to design a fusion device using a vanadium alloy, thermal and irradiation creep must be known for the conditions of application. Experiments have been done using helium pressurized tubes under neutron irradiation, and deformation has been determined for low exposure levels. One experiment was carried out in the HFIR in a shielded experiment to reduce transmutation of vanadium to chromium to acceptable levels.[1] Another experiment was carried out in EBR-II in a dynamic helium charging experiment (DHCE).[2] In this experiment, helium was introduced through the production and decay of tritium. This was a preliminary experiment, and the desired levels of helium were not achieved, but future such experiments are expected to simulate fusion parameters.

The difficulty in complex experiments is sorting out the effects of each component of the environment. The effect of temperature alone, of helium, and of atomic displacements must be separated in order to interpret the results to the extent of permitting extrapolation to real-life exposure levels. Helium by itself has been shown to decrease ductility in vanadium alloys. An example of this behavior is shown in Fig. 1 where V-20Ti was cyclotron injected with helium to levels of 90 and 200 at. ppm.[3] Helium embrittlement is evident at test temperatures above about 600°C. The effect of helium as a function of temperature and concentration must be understood in order to predict behavior in the presence of high energy fusion neutrons. Fluence and temperature dependence of helium embrittlement is very different from irradiation embrittlement which is predominant at lower temperatures in refractory metals as shown in Fig. 2 for V-4Cr-4Ti.[4]

As a first step to understand deformation in vanadium alloys, thermal creep tests have been conducted with V-4Cr-4Ti in an ultra-high vacuum environment with early results shown in Fig. 3.[5] For refractory metals such as vanadium, even the highest vacuua attainable will not prevent oxygen from diffusing into vanadium. The result is that the alloy is continuously hardened during the test. The increase in oxygen was in fact documented for a specimen exposed to the vacuum environment at 800°C for 2812 hours.[5]

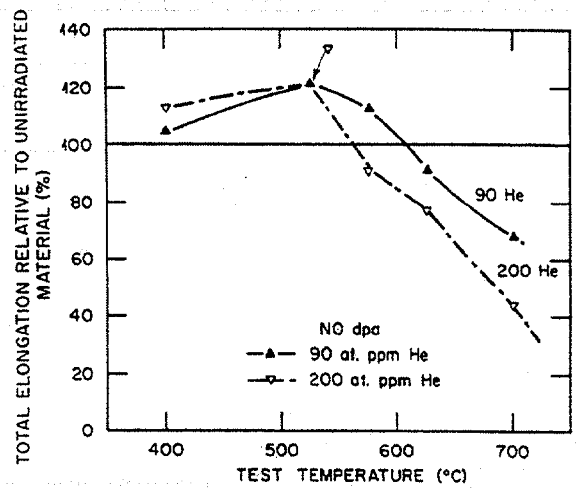

Fig. 1. Relative tensile elongation of V-20Ti following cyclotron implantation of helium.

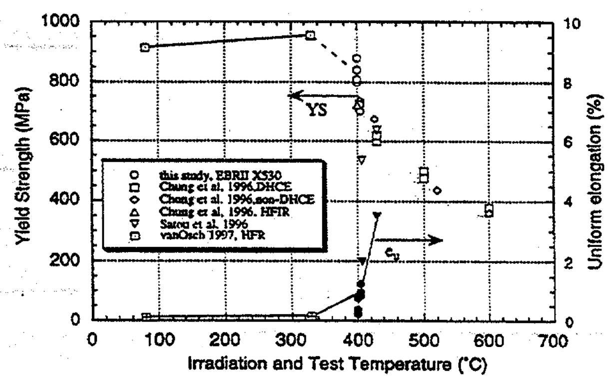

Fig. 2. Yield strength and uniform elongation of V-(4-5)Cr-4-5)Ti alloys irradiated and tested at temperatures in the range of 80-600°C. Displacement levels are in the range of 4-6 dpa.

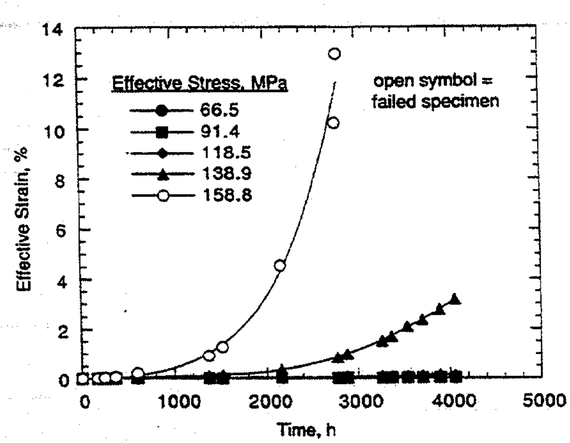

Fig. 3. Thermal creep strain from pressurized tubes of V-4Cr-4Ti exposed to a vacuum environment at 700°C.

The present experiment is designed to make similar measurements, at the same temperatures, in a liquid lithium environment. In this environment, the oxygen level is expected to slowly decrease. This effect has been demonstrated rather dramatically for the case of Nb-1Zr which was irradiated in EBR-II for a period of about 2 years in lithium at about 1200°C.[6] Results are shown in Fig. 4 where strength clearly decreased during the irradiation. Ductility correspondingly increased as can be seen in Fig. 5. Since the fusion environment will expose vanadium alloys to liquid lithium, used as a coolant, this is the relevant environment. Comparison of the Li environment tests with the vacuum tests will determine the effect of oxygen. It will also support future tests where helium is introduced in the absence of irradiation.

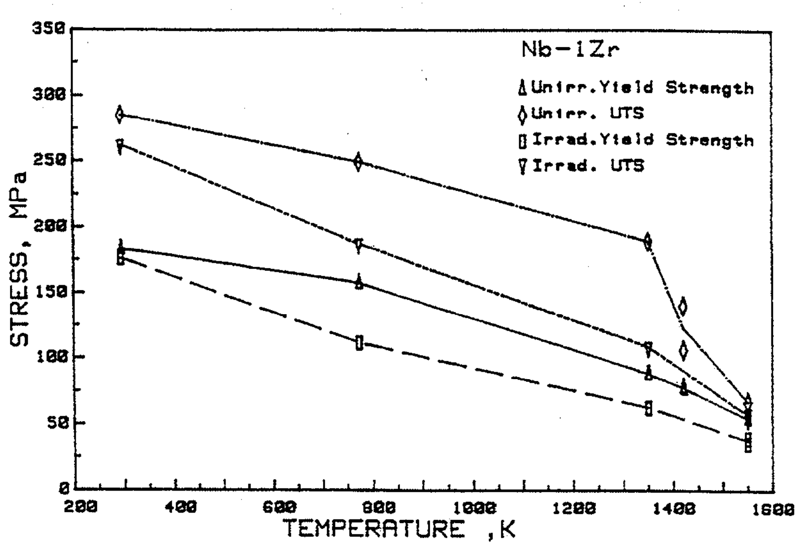

Fig. 4. Yield and ultimate tensile strength of Nb-1Zr irradiated at 1200-1340°C to a fluence of 1.9 x 10^{26} n/cm^2 (E>0.1 MeV).

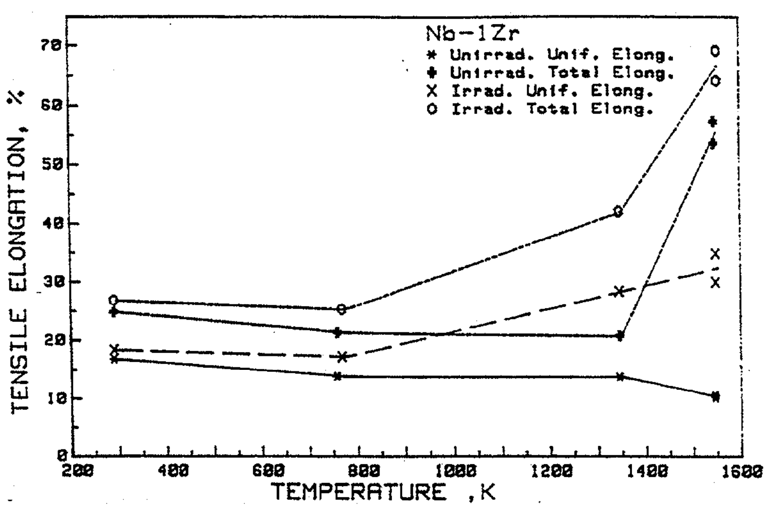

Fig. 5. Uniform and total tensile elongation of Nb-1Zr irradiated at 1200-1340°C to a fluence of 1.9 x 10^{26} n/cm^2 (E>0.1 MeV).

EXPERIMENTAL METHODS AND PROGRESS

The Li creep program will employ the methods used for study of irradiation creep, pressurized tubes. Specimen preparation and measurement are done in the same manner using helium as a fill gas and making a series of 500 diameter measurements in a helical pattern on the central 12.7 mm of the 25.4 mm long tube.

The pressurized tubes will be exposed to liquid lithium contained in a retort of molybdenum. The retort is sealed with a vanadium gasket. Figure 6 shows the first prototype of the retort. The lithium is contained entirely in a refractory metal vessel. As a prototype for the next phase of the project, exposure to tritium to form helium, a tritium barrier of quartz is in place around the molybdenum retort. At a temperature of 800°C, 4 x 10^5 Ci/yr are expected to diffuse through the Mo tube. The quartz barrier, which has a tritium permeation rate several orders of magnitude lower, is necessary to prevent tritium escape. A gage is connected to indicate when the partial vacuum in the quartz tube has been spoiled by diffusion of tritium through the molybdenum. A KF flange is used to seal the retort so that it can be easily removed. The retort is put in place in a vertical tube furnace.

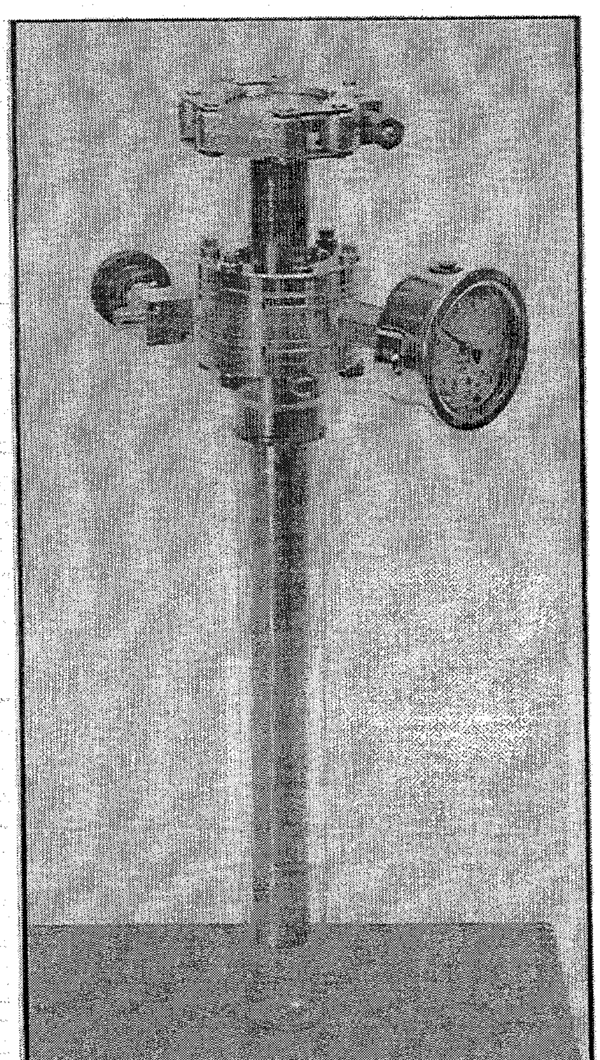

Fig. 6. Retort for liquid Li containment. A later modification had a pressure sensor added.

Two units are shown in Fig. 7 which shows a newer design in which a pressure sensor has been added to the retort. A small molybdenum tube extends above the retort and connects to a stainless steel elbow connecting to a digital pressure sensor. It was not desired to have stainless steel in the retort, but a refractory metal pressure sensor was not available for the required pressure range. The stainless steel is in a region that is well below 100°C so that Li is expected to condense and solidify well before reaching the stainless steel. The 90% bend was introduced to avoid a direct path for high temperature black body radiation to impinge on the pressure diaphragm. The pressure sensors are incorporated to indicate failure of a pressurized tube. The pressure is recorded at short intervals on a magnetic medium so that the time of tube failure can be determined.

The furnaces and retort can operate in air. However, for ease of removing specimens for measurement and for safety reasons, the furnaces are operated in a glove box with an argon atmosphere. The glove box, pictured in Fig. 8 has purification systems for oxygen, water, and nitrogen with the capability of reaching levels of each below 1 ppm. At the present time, only oxygen and moisture are monitored, by electrochemical sensors. Moisture is below 1 ppm, and oxygen is at 1 ppm. Further evaluation of the atmosphere is being made at the present time.

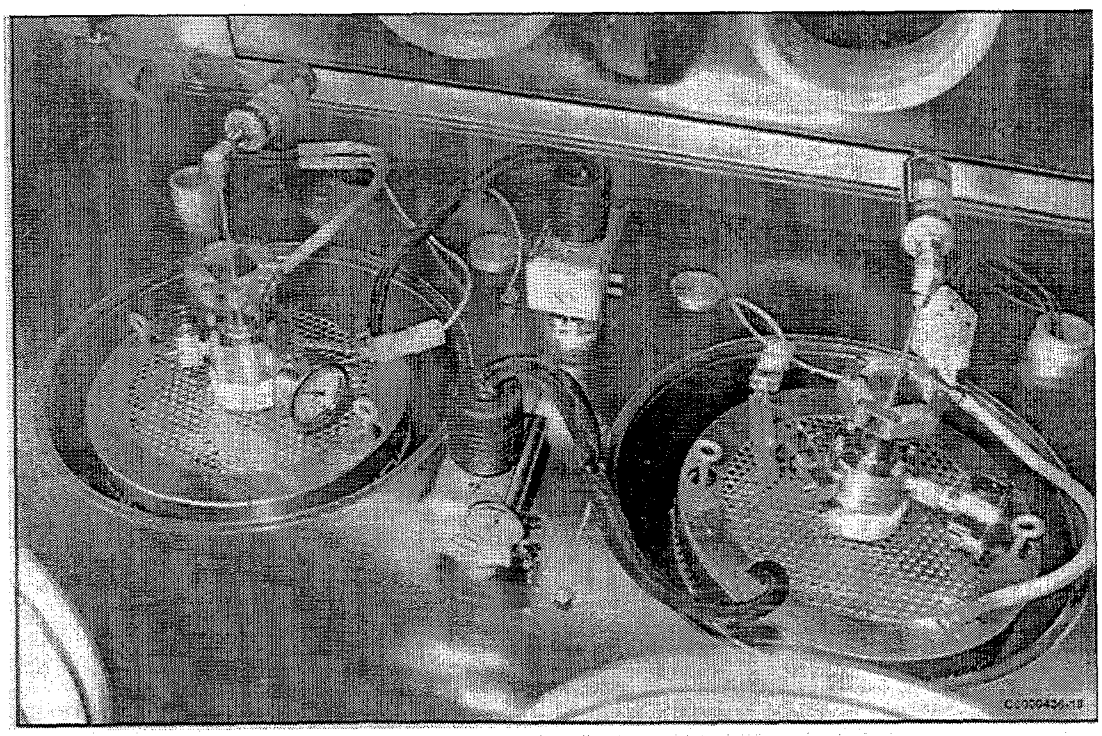

Fig. 7. Two retorts in place in furnaces positioned in an inert gas glove box. Pressure sensors appear above the retort flanges.

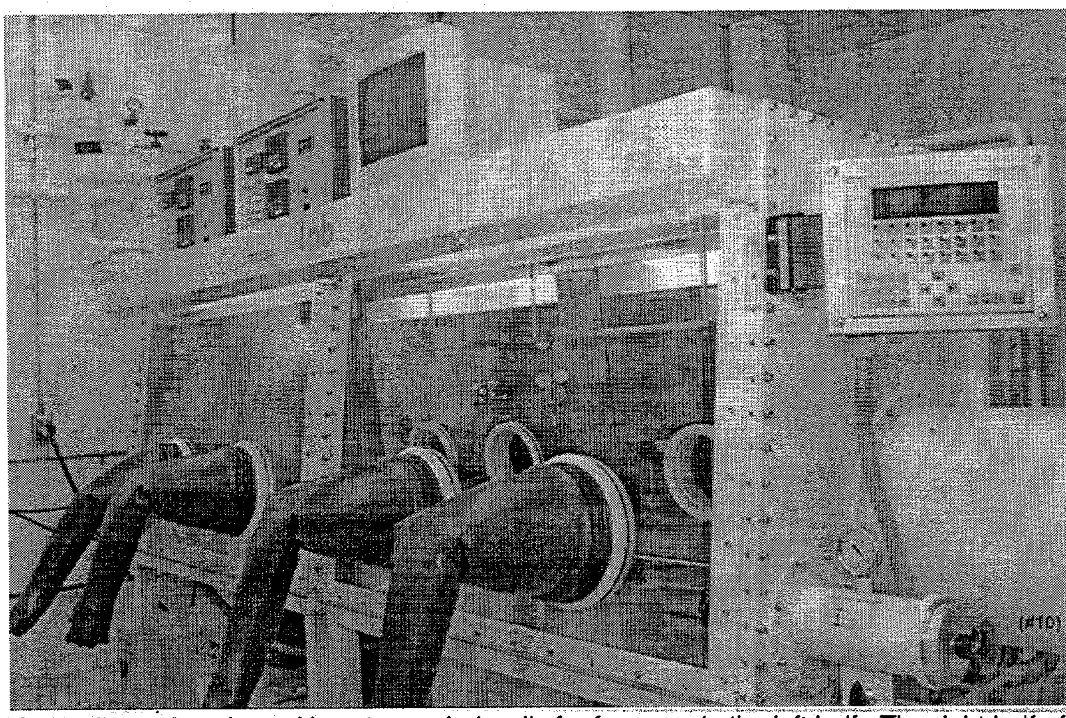

Fig. 8. Inert glove box with water cooled wells for furnaces in the left half. The right half of the glove box is for handling the tubes when removed from the liquid Li.

The glove box permits the specimens to be removed while the Li is liquid. It is planned to reduce the temperature of the Li to about 200°C, just above the melting point, and remove the KF flange seal. The specimen rack can then be lifted out of the retort. It is expected that the residual Li will be removed by dipping in hot silicone oil. With this method, the Li can be removed inside the glove box.

The stress levels have been selected based on the results of the vacuum thermal creep tests. Most of the tubes have been pressurized to fail in several hundred hours, a few for a longer duration. This will allow early data to become available which will further guide the following tests. The stresses and fill pressures are shown in Table 1.

Table 1. Stresses and fill pressures for the first phase of pressurized tube samples

Hoop Stress (MPa)	Fill Pressure (psig)	Predicted Life (Hours)
700°C		
185	884	<2000
160	772	2500
140	660	3500
115	549	>5000
105	493	
80	381	
800°C		
115	497	600
105	447	900
80	345	4000
80	345	4000
60	244	>4000
35	142	

FUTURE DIRECTIONS

The tests are planned to begin in the next reporting period. To complete the understanding of deformation behavior, the Li and vacuum tests must be conducted. Irradiation tests to determine the effect of atomic displacements have been conducted and continue to explore higher fluences and an appropriate range of temperatures. The effect of helium generated during the test by tritium decay is now being planned. This series of tests in intended to be done in conjunction with a DHCE experiment designed to reach fusion He/dpa ratios. The resulting set of data should permit understanding vanadium deformation in a fusion environment.

CONCLUSIONS

1. In order to understand the mechanisms of deformation under irradiation in the fusion environment, the fusion effects must be separated.

2. The present experiment is designed to evaluate thermal creep without the interference of oxygen. This is essential to evaluating the true thermal creep and to evaluating creep in a lithium cooled fusion blanket.

3. Temperature and stresses have been selected based on data from the vacuum creep effort. The two phases of the project will continue to be coordinated and conducted interactively.

4. A Li environment creep system has been designed and built and is in the final testing phase prior to introduction of lithium.

REFERENCES

1. H. Tsai, R.V. Strain, M.C. Billone, T.S. Bray, D.L. Smith, M.L. Grossbeck, K. Fukumoto, and H. Matsui, "Study of Irradiation Creep of Vanadium Alloys," Fusion Materials Semiannual Progress Report for Period Ending December 31, 1999, DOE/ER-0313/27 (2000) pg. 65.

2. H. M. Chung, B.A. Loomis, and D.L. Smith, " Prpoerties of Vanadium-base Alloys Irradiated in the Dynamic Helium Charging Experiment," J. Nucl. Mater. 233-237 (1996) 446.

3. M. P. Tanaka, E. E. Bloom, and J. A. Horak, "Tensile Properties and Microstructure of Helium Injected and Reactor Irradiated V-20Ti," J. Nucl. Mater. 103 & 104 (1981) 895.

4. S. J. Zinkle et al. "Effect of Fast Neutron Irradiaiton to 4 dpa at 400°C on the Properties of V-(4-5) Cr-(4-5)Ti Alloys," Fusion Materials Semiannual Progress Report for Period Ending December 31, 1996, EOE/ER-0313/21 (1997) 73.

5. R. J. Kurtz and M. L. Hamilton, "Biaxial Thermal Creep of V-4Cr-4Ti at 700°C and 800°C," Fusion Materials Semiannual Progress Report for Period Ending June 30, 1999, DOE/ER-0313/26 (1999) 3.

6. M. L. Grossbeck, R. L. Heestand, and S. D. Atkin, "Effect of Irradiation on the Tensile Properties of Niobium-Base Alloys," 4th Symposium on Space Nuclear Power Systems (1997) 151.