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DEVELOPMENT OF PRESSURIZED TUBE SPECIMEN FOR CREEP TESTING OF BERYLLIUM - W. S. Neef, R. W. Moir (Lawrence Livermore National Laboratory), E. K. Opperman (Westinghouse Hanford Company), and M. L. Hamilton (Pacific Northwest Laboratory)

PURPOSE

The purpose of this work was to demonstrate that creep tests could be performed on beryllium in the same pressurized tube geometry as is commonly used in the FFTF/MOTA.

SUMMARY

The ability to fabricate a pressurized tube specimen from beryllium was successfully demonstrated. The specimen failed at a midwall hoop stress of about 32 ksi in a burst test at 500°C.

PROGRESS AND STATUS

Introduction

Most of the proposed ITER blanket designs call for the use of beryllium as a neutron multiplier to increase the tritium breeding ability of the blanket. In addition to its excellent neutron multiplication characteristics, it is also a low activation material with high thermal conductivity. The main issues related to the use of beryllium focus on thermal and tritium transport, mechanical performance, and compatibility.^[1] As a nonstructural material that will probably rely on stainless steel for its support, the most important performance questions concern deformation, stress on structural components and thermally induced cracking. Due to the previous use of beryllium in both the fission reactor and aerospace programs, a significant data base exists for the thermal, mechanical, physical and irradiation behavior of beryllium, primarily in the form of relatively dense material containing 1 to 2 weight percent BeO. Lower density forms of beryllium are proposed, however, for ITER blanket designs.

The baseline physical properties of beryllium are fairly well understood.^[1] Mechanical properties, however, are rather sensitive to microstructural variations as well as impurities, both of which are dependent on fabrication techniques. While beryllium will not be a structural component in the blanket, it is nonetheless important to identify conditions of differential thermal expansion, swelling and creep where the material will crack. Only minimal data are available on the effects of radiation on the properties of beryllium in the temperature range of interest. In particular, irradiation creep needs to be determined to predict the stress relief arising from stresses generated by differential swelling and by contact between beryllium and steel.

Creep data on beryllium are virtually non-existent, particularly under neutron irradiation. One of the most successful means of generating irradiation creep data has been through the use of pressurized tubes in the FFTF/MOTA. The current effort was designed to demonstrate not only that such specimens could be successfully fabricated from beryllium but also that burst tests on such specimens would provide valid data, i.e., that failures would occur in the main body of the tube rather than in association with the end hardware attachments.

Experimental Procedure

Pressurized tube specimens comprise a tube and two end caps, one of which has a small machined hole which is closed with a laser weld after specimen pressurization. The end caps are typically made of the same material as the tube and are welded to the tube by an electron beam process. Welding in this case was viewed as undesirable due to the likelihood of enhanced susceptibility to radiation damage in the recrystallized zone occurring in the weld joint. Brazing was considered unacceptable because no suitable braze material is compatible with the sodium coolant in FFTF. A diffusion bonding technique was therefore developed to enable the end caps to be attached to the beryllium tube.^[2] The bonds were leak checked to verify the integrity of the bonding technique and a pressure test was performed to demonstrate the strength of the bonds. While a number of the specimens were actually fabricated, ultimately only one leak-tight specimen was obtained.

Results and Discussion

Brush Wellman provided the beryllium used for specimen fabrication. It was made to Lawrence Livermore National Laboratory specification MEL 1319, which is similar to Brush Wellman specification S-65. It contains ~1% BeO and has an average grain size (i.e., was fabricated from an average powder size) of ~12 μm . Nominal room temperature values of yield strength and fracture toughness are 35 ksi (minimum) and 10 ksi(in)^{1/2}, respectively (241 MPa and 11 MPa(m)^{1/2}).

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Drawings of the specimen components are shown in Figure 1a. The beryllium tube and end caps were machined from solid rod stock to very tight tolerances to ensure a successful diffusion bond. The thermal expansion characteristics employed are given in Figure 2. The tube specimen was nominally 0.1800 ± 0.0005 inches (4.572 ± 0.0127 mm) in diameter with a wall thickness of 0.0145 inches (0.3683 mm). The wall thickness was reduced slightly (0.0005 inches, or 0.0127 mm) at the ends to create a ledge on which the end caps rested. The end caps were straightforward plugs, i.e., similar to the standard end cap but without grooves for radiography, etc. The components were diffusion bonded at 1100°C for one hour in a vacuum chamber that measured 10^{-6} to 10^{-7} torr at room temperature.

The first bonding attempt employed a molybdenum fixture split at its center plane and bolted together. The thin film of release agent between the two halves of the fixture led to a slight loss of axial symmetry within the fixture and resulted in small leaks in the finished specimen at positions located 90° from the split line of the fixture.

The second attempt successfully employed both beryllium rings and molybdenum backup rings, as shown in Figure 1b. The beryllium rings were placed on the outside of the specimen to facilitate the bonding process, as shown in Figure 1b, while the molybdenum backup rings were used to hold the assembly together. No attempt was made to prevent the beryllium ring from bonding to the outside of the beryllium tube; while the ring was left in place for the current demonstration, it was to be machined away for any creep tests placed in the FFTF/MOTA. The molybdenum rings were allowed to fall off the assembly as it cooled from the diffusion bonding temperature.

The molybdenum rings were 0.25 inch (6.35 mm) thick and measured 1.0 inch in outer diameter by 0.50 inch inner diameter (25.4 x 12.7 mm). The beryllium rings were 0.25 inch thick, 0.50 inch in outer diameter, and 0.18 inch inside diameter (6.35 x 12.7 x 4.57 mm). No drawings exist for these components; rather, the rings were machined to fit the tube so the nominal diametral clearance was 0.001 inch (0.025 mm) at both the 0.18 and 0.50 inch (4.57 and 12.7 mm) diameters.

A Cu-Ni tube was brazed with Q-SIL (28% copper, balance silver) to the fill plug to pressurize the specimen for this demonstration as shown in Figure 1b. Titanium hydride powder was mixed in a 30:1 ratio with a lacquer-based carrier and painted on the surfaces to be brazed to enhance the wetting of the beryllium by the braze. Brazing a fill tube was chosen in this case instead of using the standard laser-welded fill hole to facilitate leak testing of the assembly with helium prior to the burst test. The specimen was soaked at 760°C for five minutes prior to brazing, which was performed at temperatures that ranged from 780 to 810°C in a vacuum chamber that measured 10^{-6} to 3×10^{-7} torr at room temperature. If the wetting agent had not been used, much higher temperatures would have been required. The specimen was allowed to cool overnight after brazing the pressurization tube into place. Several views of the finished assembly are shown in Figure 3.

The burst test was performed at 500°C in air after stabilizing at the test temperature for about four hours. The pressurizing medium was helium. The pressure was increased two times per minute, as shown in Figure 4, at an average rate of about 0.775 ksi/minute (5.3 MPa/minute) until failure occurred at an internal pressure of 6.52 ksi (45 MPa), corresponding to a midwall stress of about 32 ksi (220 MPa).^[2] The tube ruptured with ~3% ductility.

The ruptured tube is pictured in Figure 5. The burst was a small rupture in the middle of the tube, shown at higher magnification under a scanning electron microscope in Figure 6. Figure 7 shows a view inside the crack at the location indicated by the arrow in Figure 6. An optical metallograph is shown in Figure 8 of the diffusion bonds between the tube and both the end plug and ring, taken at the end of the tube.

Figure 8 demonstrates that the bond between the tube and the end cap was quite good, with no visible gaps in the metallographic section. A large amount of porosity is evident on the surface of the tube in Figure 6. The same porosity is visible in Figure 8, where it is clear that the pores on the outer walls of the tube have opened up significantly, presumably during the burst test. The fracture surface shown in Figure 7 appears to show a reasonable amount of localized deformation, most likely a result of shearing individual grains until the pores link up.

CONCLUSIONS

Pressurized tubes can be fabricated from beryllium with beryllium end plugs. Failure in a pressure ramp test at 500°C occurred at a stress of 32 ksi (220 MPa).

FUTURE WORK

Specimen fabrication should be further refined to provide pressurized tubes without beryllium rings on the ends. The parameters for welding of the laser fill hole should be developed.

Figure 1a. Components of beryllium pressurized tube specimen: beryllium tube, bottom plug and top fill plug. Dimensions given in inches.

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Figure 1b. Pressurized tube assembly with beryllium rings and molybdenum backup rings. Dimensions given in inches.

Figure 2. Thermal expansion characteristics of beryllium compared to other materials.

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Figure 3. Pressurized tube of beryllium after removal of molybdenum backup rings, showing beryllium rings attached to ends of specimen.

Figure 4. Pressure ramps data for burst test at 500°C.

Figure 5. Rupture tested specimen of beryllium showing failure location

Figure 6. Scanning electron micrograph of crack in beryllium burst test tube.

Figure 7. Scanning electron micrograph of inside of crack at location shown by arrow in previous figure.

Figure 8. Optical metallograph showing porosity, bond between beryllium ring and beryllium tube (left arrow), and bond between beryllium tube and beryllium end cap (right arrow).

REFERENCES

1. ITER Materials Data Base Report, to be published.
2. W. S. Neef, Beryllium Pressure Vessels for Creep Tests in Magnetic Fusion Energy, UCRL-ID-104441, July 20, 1990.

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