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GRAPHITE TO INCONEL BRAZING USING ACTIVE FILLER METAL*

J. F. King, F. W. Baity, J. C. Walls, and D. J. Hoffman

Oak Ridge National Laboratory
P. O. Box 2008
Oak Ridge, TN 37831-6096

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ABSTRACT

Ion cyclotron resonant frequency (ICRF) antennas are designed to supply large amounts of auxiliary heating power to fusion-grade plasmas in the Toroidal Fusion Test Reactor (TFTR) and Tore Supra fusion energy experiments. A single Faraday shield structure protects a pair of resonant double loops which are designed to launch up to 2 MW of power per loop. The shield consists of two tiers of actively cooled Inconel alloy tubes with the front tier being covered with semicircular graphite tiles. Successful operation of the antenna requires the making of high integrity bonds between the Inconel tubes and graphite tiles by brazing.

The Faraday shield tubes for the TFTR and Tore Supra rf antennas are 9.5 mm diam and 440 to 480 mm in length and are made of Inconel 625. This alloy was chosen for its high tensile and fatigue strength which will be required to withstand the disruption loads experienced during service. These tubes, which are copper plated for improved electrical conductivity, are protected from the plasma heating flux by graphite tiles brazed to the front side. The differences in thermal expansion and mechanical properties of the Inconel and graphite makes joining by brazing difficult. The magnitude of the residual stresses in the brazed tile was of concern in this combination since cracking of

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the graphite could occur during cooling from the brazing temperature. A very fine-grained, isotropic graphite with suitable strength and thermal expansion properties was selected for this application. The braze material for this joint was Ticusil, an active metal braze alloy containing silver-copper-titanium produced by GTE WESGO.The residual stress state in the braze joint was determined by utilizing a 2-D finite element model analysis with the MCS/NASTRAN code. A nonlinear analysis technique was utilized to obtain the stress state in the graphite and it was found to be below the failure criteria.

Brazing tests were performed for joining the graphite tile to the copper plated Inconel tubes. Initial results were inconsistent for the bond area between the two components. Detailed analyses of the test brazes revealed that several problem areas had contributed to the variability of the bonds and to the presence of large voids in the braze. The first of these was the design of the joint and the very accurate control of joint tolerances at the brazing temperature. It was necessary to design the brazing fixtures to accurately align each of the 18 to 20 tiles required for each tube. These fixtures were fabricated from graphite, Inconel, and TZM to match the expansion of the tiles and tube during heat up to the brazing temperature. The final problem area which affected the yield of acceptable tubes was the control of the vacuum furnace gas pressure and temperature. Thermocouples were placed inside the Faraday shield tubes to assure the accurate attainment of brazing temperature. Outgassing of the graphite during heat up was found to reduce the braze bond quality. The graphite was cleaned and baked at 1,000°C for 2 h prior to assembly for brazing. Exposure to air occurred during assembly of the parts in the brazing fixture. When the tubes were raised directly to brazing temperature after evacuation of the furnace, the rejection rate of the tubes based on a criterion of 80% bonding for the worst tile was about 33%. After instituting a bakeout in situ at 650°C for 30 min followed by an overnight evacuation of the furnace, the rejection rate was reduced to less than 10%.

Two nondestructive examination techniques were developed to inspect the braze joints in the Faraday shield tubes. These were infrared thermography and radiography. Both techniques were used for determining the integrity of the bonds but radiography was primarily used to obtain quantitative information about the unbonded flaw sizes present in the braze joints.