DEVELOPMENT AT ANL OF A COPPER-BRAZED JOINT FOR THE COUPLING OF THE NIOBIUM CAVITY END WALL TO THE STAINLESS STEEL HELIUM VESSEL IN THE FERMILAB SSR1 RESONATOR*

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Abstract

In order to reduce the sensitivity of the Fermilab SSR1 resonator to helium pressure variations, it was concluded that the cavity and helium vessel end-walls needed to be structurally coupled by means of a transition ring. The materials to be connected are Niobium and Stainless Steel. Technology previously developed for the cavity flanges consisted of a furnace-brazed joint utilizing oxygen-free electrolytic copper filler metal. Small-scale and full-scale annular samples were constructed at Argonne National Laboratory and subject to leak tests, tensile tests, thermal cycling and visual inspections to qualify the proposed joint for the structural couple.

INTRODUCTION

The design for the SSR1 resonator [1] involves a circumferential structural joint between Niobium and Stainless Steel (Figure 1). This joint is estimated to be subject to loads up to 500 psi during operation due to pressure gradients across the cavity walls and differential thermal contractions between the helium vessel and the cavity. The diameter of this joint will be about 15 inches in diameter.

A feasibility study was performed by the Argonne National Laboratory Central Shops (CS) to conceive a satisfactory joint design based on previous experience.

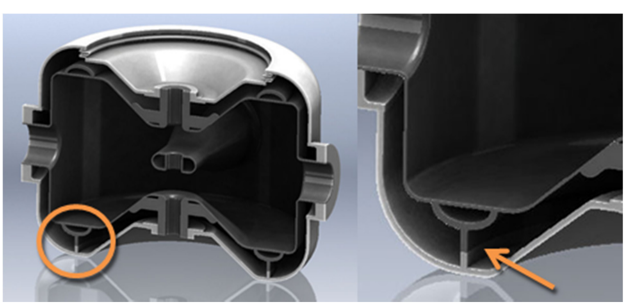

Figure 1 : Sectioned model of the SSR1 resonator (left) and a detail of the coupling ring (right) joining the niobium cavity (dark grey) to the steel helium vessel (light grey).

Tests were conducted on smaller samples to determine if the conceived joint could be properly brazed and if it could withstand thermal cycling. The strength of the brazed joint was determined by performing tensile tests at room temperature and near liquid Nitrogen temperature.

It is the conclusion of this study that acceptable braze joints can be made between Niobium and Stainless steel rings of sizes up to ~10” in diameter with CD-101 oxygen free copper filler material. These joints are capable of rapid thermal cycling between room temperature and liquid nitrogen temperatures. Ultimate tensile strength levels over 10,000 psi can be achieved at both room temperature and at liquid nitrogen temperatures. In addition to their mechanical strength, these joints are acceptable for ultra-high vacuum (UHV) service.

JOINT DESIGN

Copper brazing of Niobium to Stainless Steel has been applied to SRF cavities for more than two decades [2] The process has been adapted successfully by the CS to several projects and was recently utilized for joining the Stainless Steel flanges to the SSR1 Niobium cavity following the process described in [3].

A first design (Joint A, Figure 2) was conceived and a small sample having a diameter of 3 inches was fabricated.

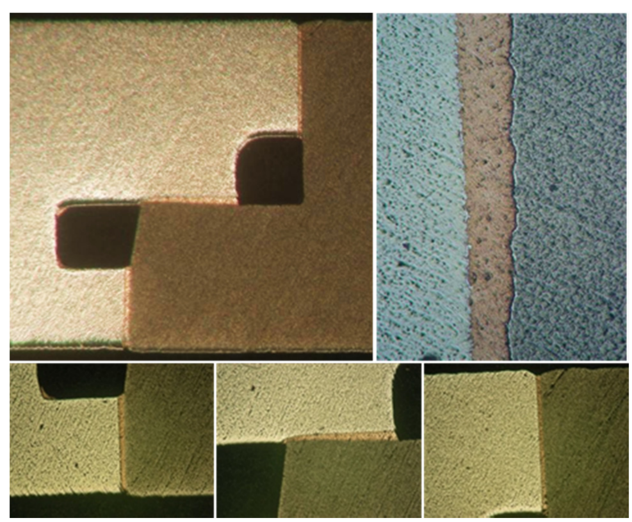

Figure 2 : Micrographs of Joint A. The stainless steel mating part is the lighter shade and the Niobium part is the darker shade. The two grooves for the filler material were machined on the stainless steel part (top left). The copper filler material can be seen between the mating parts.

The initial machining operations indicated that placing two filler metal grooves in the stainless steel posed a

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particular challenge. The filler groove on a concave portion of the step required the use of small tooling and slowed the process down considerably.

An alternative design (Joint B, Figure 3) was developed by moving one of the two filler grooves to the niobium part.

Initially, both specimens were brazed with a solid stainless steel plug in the inside diameter (Figure 4) following the common approach when mating such materials. The purpose of the plug is to facilitate expansion of the niobium during brazing as the niobium has a significantly lower coefficient of thermal expansion compared to stainless steel. This plugging technique was used in the procedure described in [3] and successfully used on many production parts.

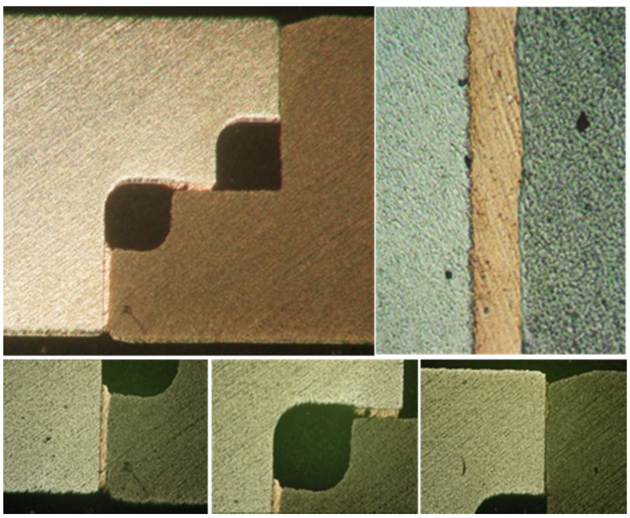

Figure 3 : Micrographs of Joint B. The color coding is the same as Figure 2. The simplified stainless steel part is visible in the top left image. The central portion of the joint is magnified in the bottom-central image, one can see that the copper filler material is non-uniform.

The results of the 3 inch specimens were successful. It was also observed that after brazing, the expansion plugs were loose to the internal diameter of the tubes. This suggested that the stepped portion of the steel piece might have acted as the expansion plug, making the steel plug redundant. This finding is of great importance for the manufacturing of such components. As a result of the process, the steel plugs typically tend to damage the internal diameter of the niobium parts requiring the removal of a certain thickness of material by turning. Furthermore, the plugs end up being trapped in the niobium parts requiring additional work. Each specimen was sectioned and polished to produce micrographs shown in Figure 2 and Figure 3. The quality of the joints appeared satisfactory over-all with continuous flow of copper filler throughout the joint areas. It was observed that Joint B was easier to manufacture. (Figure 3) The joint is comprised of three separate brazed areas, however Joint B had a non-optimal central area that generated concern due to the small size. The joint design was modified to improve the amount of brazed cross sectional area by increasing the length of the central joint.

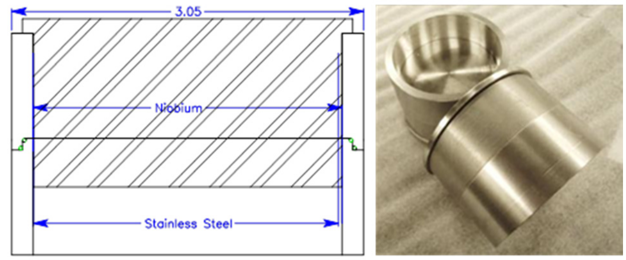

Figure 4 : A sketch (left) and a picture (right) for the trial pieces with expansion plugs installed.

Larger trial pieces, were manufactured to verify the improved Joint B (longer center section). These larger pieces had a diameter of 10.6” as shown in Figure 5. One trial piece was brazed with a 1 inch thick plug and the other was brazed experimentally with no plug at all (Figure 6).

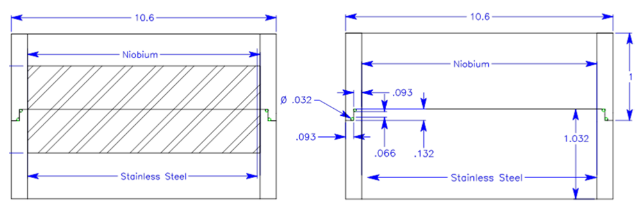

Figure 5 : Geometry of the larger trial pieces. Shown with steel plug (left) and without the plug (right).

Figure 6 : The two large trial pieces. One without plug (left) and one with a 1 inch thick plug (right).

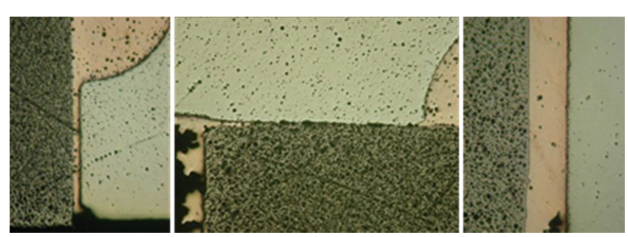

Figure 7 : Micrographs of the large trial pieces showing uniform copper filler material in each of the three areas of the joint.

The brazing results were satisfactory for both specimens. The micrographs of one of the specimens are shown in Figure 7. It was furthermore confirmed that the stainless steel plug was in fact redundant.

BRAZING

The niobium parts were ultrasonically cleaned and chemically etched for three minutes and rinsed with deionized water and alcohol. The stainless steel parts were degreased, rinsed and heat-cleaned in the vacuum oven at 1000 °C. Two CD-101 copper wires having a diameter of 0.030 inches were placed in the grooves machined in the joint. The parts were assembled and a load of 1 psi was applied to the joint.

The brazing was done in vacuum and followed the typical brazing steps with a slow ramp-up of the temperature to slightly below the liquidus point, a hold to stabilize the temperature in the parts and a faster rise to the braze temperature, a hold of a few minutes and cool down to below 100 °C. The furnace cycle charts for the small trials as well as the larger trials are shown in Figure 8.

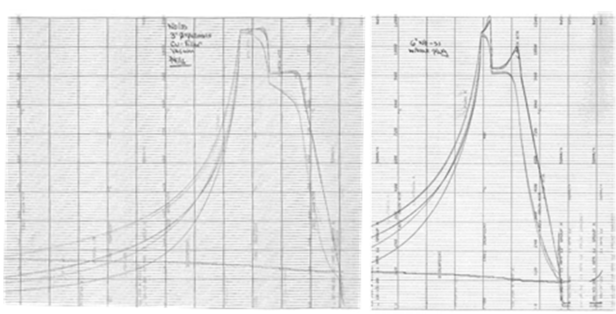

Figure 8 : Brazing charts show the curves of temperature vs. time for the small trial pieces (left) and large trial pieces (right). Time is plotted from right to left.

TESTING

A campaign of tests was administered to the brazed components to assure the robustness of the design and the strength of the joint.

The parts were initially inspected visually to see if filler material was evident on the outer surfaces of the joints. Helium leak testing was performed to check the integrity of the joint using mass spectrometer leak detection (MSLD). The components were later subjected to submersion in liquid Nitrogen 10 times, interposing rests at room temperature to reach 68 F. A second MSLD leak test was conducted after the thermal cycling.

The specimens were sectioned and images were taken at various magnifying ratios.

Strips having a width of 0.75 inches were cut from the joints and tensile tests were conducted at room temperature and at near liquid nitrogen temperature (see Figure 9). The strength of the various joints was qualified using the lowest value recorded among all samples of each joint. The ultimate strengths appeared independent from the temperature. The strengths recorded were 11,402 psi (joint A), 9,787 psi (joint B) and 13,848 psi (final joint).

CONCLUSIONS

The results of this program conclude that a step style joint between Niobium and Stainless Steel can be successfully used in small and large diameters (3-10.6 inches). It is postulated that even larger and smaller diameter components could be successfully brazed with the same process. The joint employs a locking configuration and no internal expansion plugs are needed for brazing. The joining parts can be near net shape (diameter and length) as there is no damage to the interior of the parts typically caused by the plug piece coming in contact with the Niobium. This will be a considerable cost saving aspect.

The resulting joints are MSLD He leak tight and are robust enough to take thermal cycling typical of resonator service. Finally, tensile strengths in excess of 10,000 psi are achievable with the new joint design.

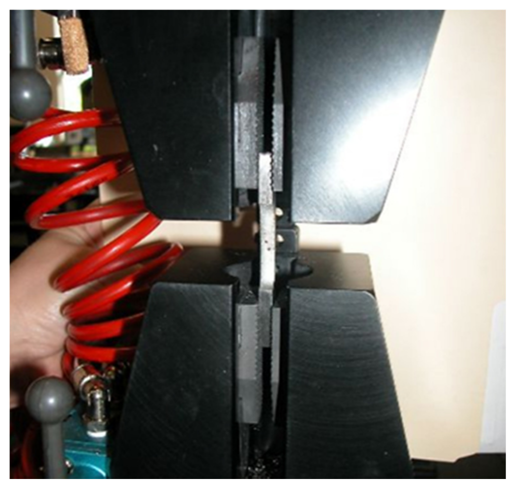

Figure 9 : Setup for a tensile test on a strip cut from one of the large sized specimens.

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