NIOBIUM TO STAINLESS STEEL BRAZE TRANSITION DEVELOPMENT

J.D. Fuerst*, W.F. Toter, K.W. Shepard, ANL, Argonne, IL 60439, USA

Abstract

We present results of an R&D program to develop and test a reliable cryogenic leak-tight, copper-brazed transition between niobium and stainless steel for use in superconducting niobium cavities. We have chosen to make the integral helium container that houses a niobium cavity of stainless steel rather than titanium both for ease of fabrication and also for low cost. Other techniques for joining niobium to stainless steel such as electron beam welding (EBW) and explosive bonding have not in our experience provided the quality and reliability needed for the intended service. The braze technique described is a further development and simplification of a technique developed several years ago at CERN. Our technique has improved on the CERN method in requiring less machining and a simpler set-up, while producing a very robust, void-free, and leak tight joint. The braze joint withstands mechanical load, repeated thermal cycles, and can tolerate subsequent EBW of niobium within a few cm of the braze joint.

INTRODUCTION

ANL is developing drift-tube-loaded SRF cavities for the Rare Isotope Accelerator (RIA). These cavities feature integral stainless steel jackets serving as the liquid helium (LHe) vessel. This design requires a robust, leak tight transition between the niobium of the cavity and the stainless steel LHe tank. A technique for brazing niobium to stainless steel was developed in 1987 at CERN [1]. The process used copper filler metal, vacuum furnace brazing and a joint design in which the filler metal was inserted into the joint face. ANL decided to modify this technique to simplify fabrication and reduce cost. The resulting braze transition has shown excellent performance both in sample tests and in service on an actual cavity prototype. Fabrication is straightforward and repeatable. ANL intends to use this transition on all classes of drift tube cavities developed for RIA.

JOINT DESIGN

The desired joint configuration is shown schematically in Figure 1. It consists of a stepped niobium tube fitted to a stainless steel flange. A shoulder for braze metal is machined into the flange inner diameter at the top face. Single or multiple turns of pure copper braze metal are placed in the shoulder in contact with both the niobium and the stainless steel. Joint clearance of 0.001-0.002" must be maintained at the brazing temperature. This clearance is preserved by inserting a stainless steel plug into the niobium. This serves to expand the niobium during brazing to maintain the gap. Sharp corners at the base of the joint are broken to enhance flow of the braze metal.

*fuerst@anl.gov

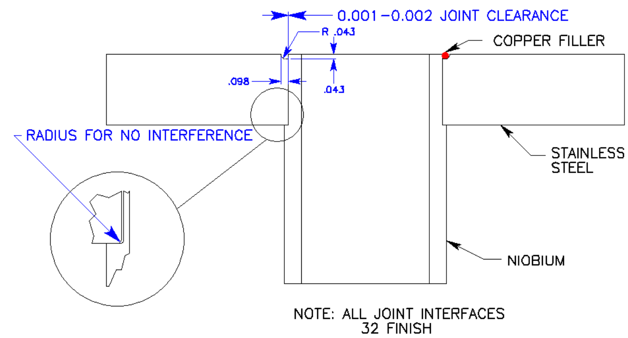

Figure 1: Braze joint configuration.

Filler Metal

The filler metal is CDA-101 high purity copper wire meeting AWS specification A5.8 BVCu01X Gr2-1992. Table 1 shows the wire chemical analysis. Joints were made with both single wraps of 0.093" dia. and 0.125" dia. wire and also with double wraps of 0.093" wire. For joints of 1" diameter and up to 0.38" thickness a single wrap of 0.093" wire was sufficient. Thicker or larger diameter joints required more wire.

Table 1: Braze wire chemistry

Element	PPM
Cu	99.99
P	2
S	5
Cd	<1
Zn	<1
Hg	<1
Pb	<1
Se	<5
Te	<5
Bi	<1
O_2	2
other	<20

Part Preparation

The niobium tube was machined to size, measured, then cleaned <24 hours before the brazing run. Cleaning consisted of an acetone/alcohol wipedown followed by chemical etching using a buffered chemical polish (BCP) solution of one part hydrofluoric acid 49% concentrate, one part nitric acid 69% concentrate and two parts phosphoric acid 85% concentrate. The niobium is kept in the BCP solution for three minutes, then rinsed with deionized water and alcohol and air dried.

The stainless steel flanges and plugs are pre-machined, then cleaned and stress relieved in the vacuum furnace at 1100 C. They are then re-measured and machined to final size. From this point on all parts are bagged and kept clean prior to the braze.

Brazing Cycle

The furnace is a three zone hearth with independently controlled top, middle and bottom heaters (Figure 2). The furnace is certified by using three calibrated thermocouples on a wire rack. Furnace runs were made both with the hearth empty and with a large load and the output of the heaters was varied so that no point in the hot zone varied from the nominal by more than 5 C.

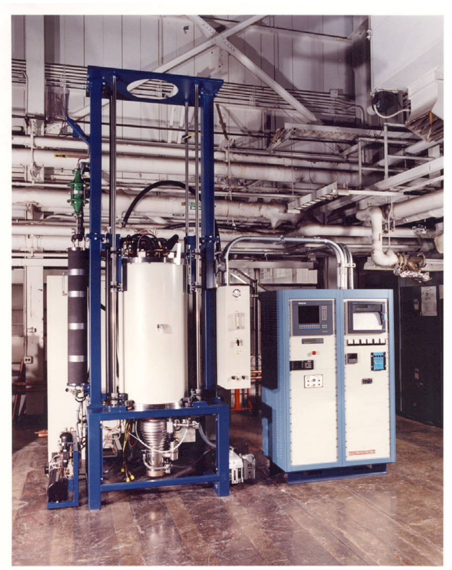

Figure 2: ANL hydrogen/vacuum furnace.

The filler metal dictated a brazing temperature of 1110 C. A typical furnace chart showing the brazing cycle is shown in Figure 3. The furnace and parts were pre-heated by ramping 20 C/minute to 960 C. At that point the hearth and parts were allowed to stabilize. The furnace temperature was then increased at 100 C/minute until thermocouples on the parts reached 1140 C. The furnace is held there for six minutes to accomplish the braze. The parts were cooled down to 100 C in vacuum, at which point the hearth was backfilled with nitrogen.

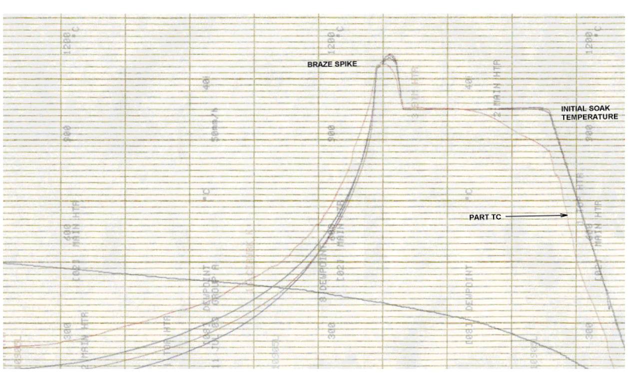

Figure 3: Furnace braze temperature cycle. Time advances from right to left.

EXAMINATION AND TESTS

Good braze joints can be verified visually by inspecting the top and bottom of the joint. Figure 4 shows photos of completed specimens. We found that insufficient braze metal (evidenced by lack of fillet on the backside) could be repaired by re-running the joint through the furnace with additional copper added to the groove. Samples were leak checked with a mass spectrometer helium leak detector. Samples were sectioned and micrographs taken at several locations on the joint.

Figure 4: Completed braze assemblies showing (top) joint top surface with braze metal groove and (bottom) joint underside showing fillet.

Scanning Electron Microscopy (SEM)

Joint cross sections were examined using SEM to determine the diffusion of elements between the stainless, copper, and niobium interfaces (Figure 5). The stainless/copper fusion line reveals an intermittent phase containing about 61% Cu and 24% Fe (Figure 6). Interestingly the niobium/copper fusion line shows a phase containing 46% Fe and 23% Nb (Figure 7), suggesting that iron has diffused across the joint through the copper. Table 2 gives the element breakdown for the transitions as well as the post-braze copper itself.

Table 2: SEM element analysis (+- 5%)

element	steel/copper interface [%]	copper [%]	copper/niobium interface [%]
Fe	24	4	46
Cr	8	1	11
Ni	3	1	2
Cu	61	93	13
Nb	1	1	23

Load Tests

A room temperature shear test was performed on a braze joint sample consisting of a 1.25" diameter niobium tube brazed to a 1" thick stainless flange. Load was applied to a stepped plug inserted into the niobium tube while the stainless flange was supported, thereby placing the joint in shear. With a joint area of 1.06 in^2, loading up to 6700 lb was accomplished without failure or plastic deformation. Above 6700 lb deformation occurred as the load was increased as high as 48000 lb without catastrophic joint failure.

Thermal Cycles

Six test joints were repeatedly cycled between room temperature and 77 K by alternatively submerging them in liquid nitrogen and water for twenty cycles. Subsequent He mass spectrometer leak checks revealed no leaks in any samples. Both TIG and EB welds representative of subsequent assembly operations were performed on samples with no leaks or joint deterioration recorded.

Five braze assemblies have been installed on ANL's prototype 2-cell spoke cavity [2]. This cavity has operated at temperatures down to 2 K without incident.

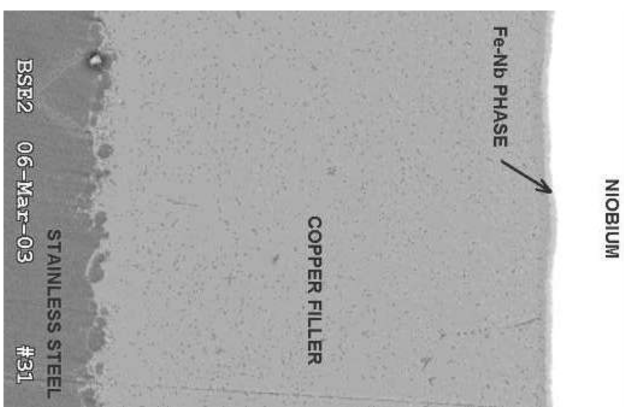

Figure 5: SEM of entire joint.

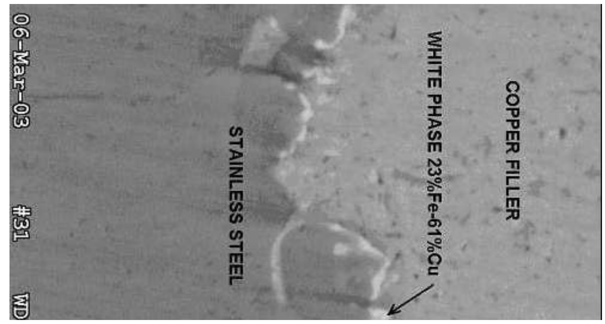

Figure 6: SEM closeup of stainless/copper transition.

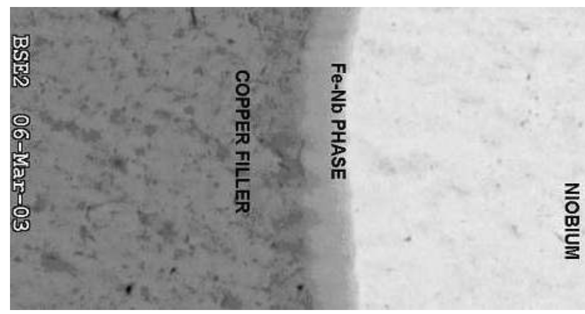

Figure 7: SEM closeup of copper/niobium transition.

CONCLUSIONS

A leak tight, reliable braze transition between niobium and stainless steel has been developed and qualified for use on drift-tube SRF cavities for RIA. The design is a modification of an existing CERN technique using pure copper braze metal. We have simplified the design to reduce cost and produce a void-free joint. The joints are successfully operating on a prototype two-cell spoke cavity.

REFERENCES

[1] Bacher, J.P., Chiaveri, E., and Trincat, B., "Brazing of Niobium to Stainless Steel for UHV Applications in Superconducting Cavities," CERN/EF/RF 87-7, 1987.

[2] Shepard, K.W. et al, "Superconducting 345 MHz Two-Spoke Cavity for RIA," PAC2003.