Analysis of Vacuum-Brazed Joints of Glidcop®

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Abstract – Gold-copper (Au-Cu) brazing of Glidcop in hydrogen atmosphere has been widely used for the components of synchrotron light sources for many years. An evaluation of Au-Cu brazing of Glidcop without copper plating of the components was presented in [1]. Recently Glidcop vacuum components of two new light source facilities, NSLS-II (BNL) and TPS (NSRRC), have been brazed in vacuum atmosphere because the vacuum brazing process is more widely available and safer to use. These vacuum brazed joints were deemed to be successful based on visual examinations, micrographs of the joints, vacuum leak tightness, and preliminary tests for the bond strength.

For a more detailed and quantitative comparison of brazing Glidcop in hydrogen and vacuum atmospheres, several braze samples were prepared identical to those reported in [1], and brazed in a vacuum oven at ANL with 50/50 Au-Cu foil and paste. The braze joints were then examined with scanning electron microscope (SEM) and tested for vacuum leak tightness and strength. In this paper we describe these recent test results together with previous evaluations performed at NSLS-II and TPS.

Keywords: Braze, Glidcop, Vacuum, Hydrogen, Strength

1. Introduction

Glidcop has been used in many light sources for high heat load components because of its high conductivity (comparable to that of OFC) as well as its high strength and fatigue life at elevated temperatures. Glidcop is frequently brazed to OFC copper and stainless steel in the assembly of vacuum components such as crotch absorbers, fixed masks and slits. There are different recommended processes for gold brazing of Glidcop, some requiring copper or nickel plating of the joints to be brazed. The brazing tests described in [1] which were made in hydrogen atmosphere showed that copper or nickel plating is not necessary for achieving excellent brazed joints.

Recently the Glidcop components for NSLS-II and TPS light sources have been brazed in vacuum atmosphere; these brazed joints were also produced without copper or nickel plating. Good vacuum-brazed joints were achieved by using a thorough chemical and mechanical cleaning procedure and by brazing at slightly higher temperatures. To further investigate the quality of vacuum-brazed joints in Glidcop, a second study was performed that duplicated the 2003 study variables with the exception of the furnace atmosphere.

2. Vacuum Brazed Components at NSLS-II

A large number of absorbers for the new NSLS-II storage ring were brazed in vacuum atmosphere (see Figure 1) and metallurgical testing procedures were performed to help characterize the quality of these vacuum brazed joints [2].

(a) Crotch Absorbers (b) Insertion Device Exit Absorber (c) Diagnostics Horizontal Scraper

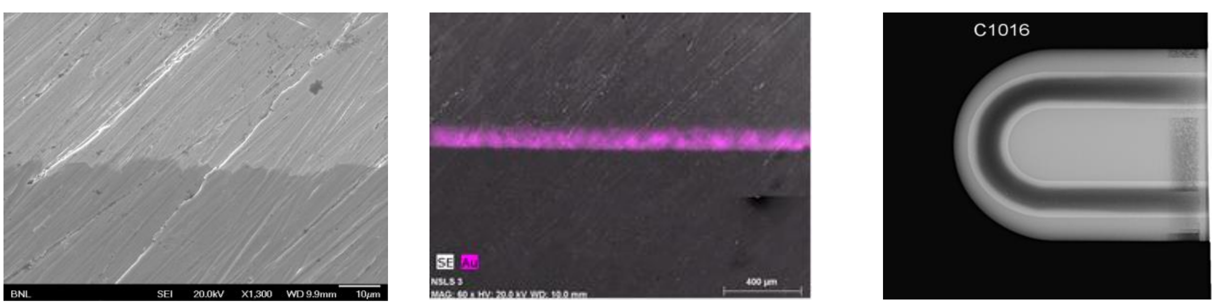
Figure 1: Vacuum brazed absorbers for the NSLS-II storage ring.

The brazing surfaces were cleaned using an ultrasonic chemical process with Citranox detergent as the primary cleaning agent. This was followed by Scotch-Brite® abrading and ethanol ultrasonic cleaning immediately before brazing. To maintain cleanliness of the parts, they were handled while wearing gloves and the work area was kept clean (HEPA filtered). Good furnace vacuum (low oxygen partial pressure) was maintained to reduce oxide formation on the parts.

50/50 Au-Cu (Premabraze® 402) and 35/65 Au-Cu (Premabraze® 407) alloys were used for brazing. During braze, the liquidus temperature was exceeded by approximately 10-20° C for 5 minutes.

Each vacuum braze joint is leak tested with a Helium Mass Spectrometer leak detector for leaks greater than $1x10^{-10}$ std-cc/sec He.

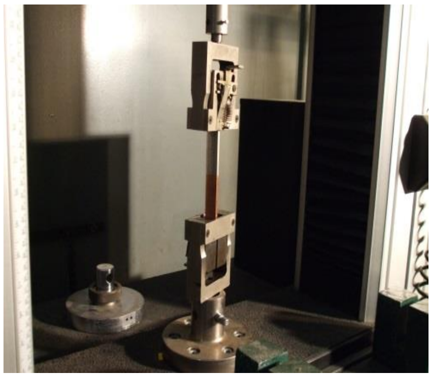
The brazed joints were inspected using micrographs, energy dispersive spectroscopy (EDS) and x-ray radiographs (Figure 2). The joint interfaces show (a) complete wetting and bonding, (b) no significant diffusion of the braze alloy and (c) void free joints.



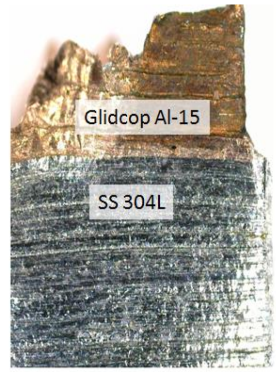
(a) Micrograph (b) EDS Image (c) X-ray Image

Figure 2: Inspection images of the vacuum brazed joints at NSLS-II, (a) micrograph of the 50/50 Au-Cu alloy to stainless steel 304L interface showing complete wetting and bonding, (b) energy dispersive spectroscopy image – chemical mapping of gold alloy at the braze interface, (c) an x-ray image of 50/50 Au-Cu braze joint between the OFC tube and Glidcop body of a crotch absorber.

A test sample having a cross section of 3 mm x 19 mm, was prepared to join Glidcop Al-15 to 304L stainless steel with 50/50 Au-Cu alloy in a vacuum atmosphere (Figure 3(a)). The specimen failed by fracture in Glidcop away from the braze interface while the brazed joint remained intact (Figure 3(b)). The applied load and stresses were not recorded during this test.



(a)



(b)

Figure 3: Tensile testing of a sample brazed at NSLS-II in vacuum atmosphere, (a) tensile test setup with sample having a cross section of 3 mm x 19 mm, (b) fracture in Glidcop Al-15 away from brazed joint.

3. Vacuum Brazed Components at TPS

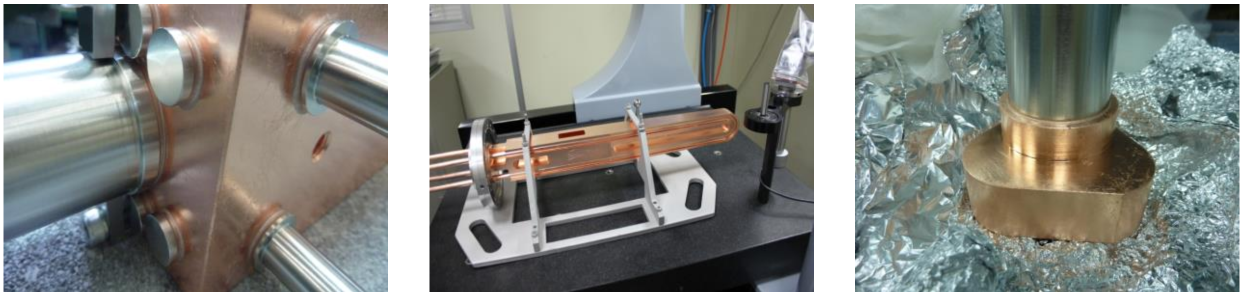
The Taiwan Photon Source (TPS) also performed a vacuum braze study for components made of Glidcop and stainless steel [3]. This vacuum braze study was necessitated from the fact that TPS was unable to find any qualified local sources that were capable of performing hydrogen furnace brazing.

Samples were made from Glidcop and 304 stainless steel with braze joints that replicated the braze joints planned for the actual components. The samples were precisely machined to provide a 50 - 100 µm diametrical clearance at braze temperature, this allows the braze alloy to flow into the joint by capillary action.

The joints were made using 50/50 Au-Cu braze alloy wire in a vacuum furnace without plating. 50/50 Au-Cu alloy was selected for both its sluggishness to flow and its lower liquidus temperature. 35/65 Au-Cu is also used when a second brazing cycle is required.

Purging with dry N2 was used successfully to shorten the time required for cool down of the work pieces. It was also found to be helpful to fire the furnace prior to brazing to ensure that it is free of contaminants. Temperature control of the furnace was based on work piece temperature not the furnace temperature; this was especially important when multiple parts were brazed.

The study demonstrated that vacuum brazing was capable of producing good quality joints for UHV service as verified by helium leak testing and Scanning Electron Microscopy analysis. Figure 4 shows some examples of vacuum brazed components of the TPS storage ring.



(a) Front End Mask (b) Crotch Absorber (c) End Absorber

Figure 4: Vacuum brazed Glidcop components at the TPS storage ring, (a) front end mask with brazed aperture tube and water fittings, (b) crotch absorber in an inspection fixture, (c) end absorber used at the end of a straight vacuum chamber.

4. Vacuum Braze Tests at ANL

A quantitative evaluation of vacuum brazed joints was performed recently at ANL by duplicating the hydrogen atmosphere brazing tests performed in 2003 [1]. In order to compare the two brazing processes (vacuum atmosphere and hydrogen atmosphere) every effort was made to duplicate the testing and evaluation parameters as closely as possible [4].

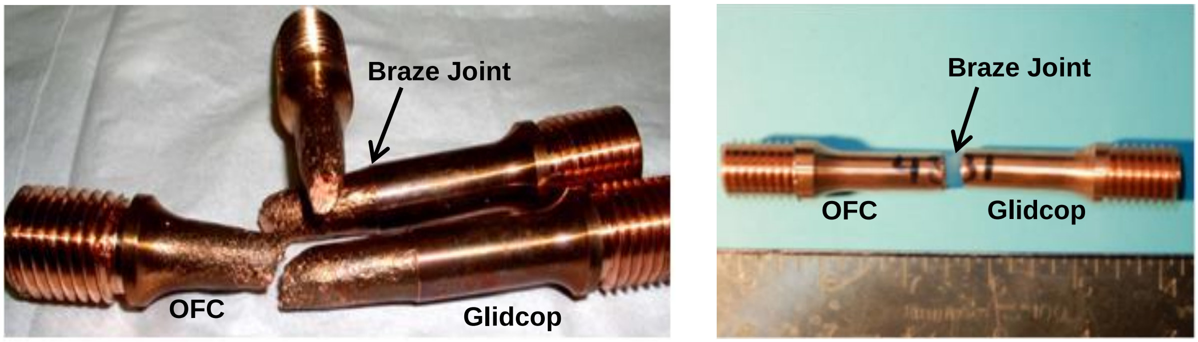
The furnace that was used in the previous brazing study [1] was also used to produce brazed joints in vacuum atmosphere so that furnace cycle times and temperature profiles could be duplicated. The furnace has been retrofitted with a new Honeywell HC900 controller and is now equipped with Spec-View© operating system for temperature monitoring and chart recording. These new features did not change any of the thermal dynamic properties of the furnace. The programs and other furnace associated equipment such as the hearth configuration, heaters, thermocouple types, SCR controllers, shields, mechanical pumps, vacuum pumps, and cooling baffles remained the same as before.

Materials used for this evaluation are identical to those used in the previous study [1]. Base materials used to prepare braze samples include Certified Glidcop AL-15, OFC certified to C101 ASTM B-152 and ASTM F68 standards, and 304 stainless steel per ASTM A213. Brazing filler metal used was (50/50 Au-Cu) in the form of both paste and foil which were certified by Morgan Advanced ceramics.

Braze sample preparation, pre-braze cleaning and handling procedures were also identical to those used in [1]. Machining finishes of the brazing surfaces were verified as RMS 32.

4.1 Tensile Strengths of Glidcop to OFC Brazed joints

Four Glidcop to OFC samples were vacuum brazed then machined and tested per ASTM E8 standards. These tests showed that, unlike the specimens brazed in hydrogen atmosphere [1] which failed in the OFC after considerable necking (Figure 5(a)), the vacuum brazed specimen separated at the brazed joints without significant necking (Figure 5(b)).



(a) (b)

Figure 5: Glidcop Al-15 to OFC tensile test specimens brazed at ANL, (a) hydrogen brazed specimens failed in the OFC after significant necking [1], (b) separation at the vacuum brazed interface.

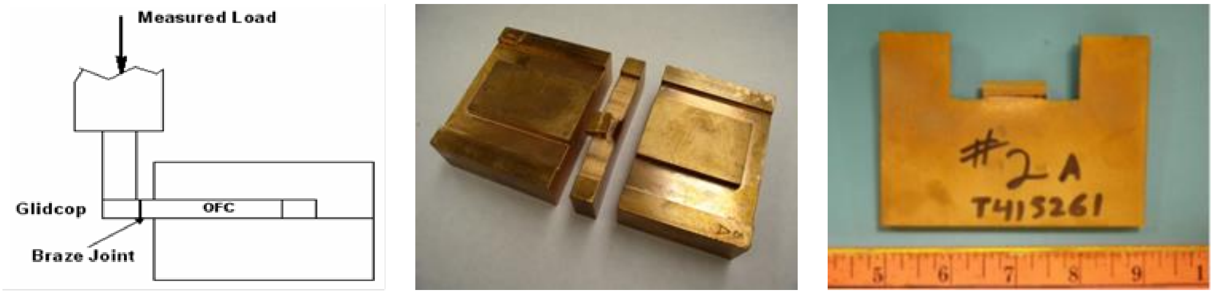
The vacuum brazed specimens failed at stress levels that were significantly lower than those brazed in hydrogen atmosphere as shown in Table 1.

Table 1. Mechanical properties of brazed joints of Glidcop Al-15 in hydrogen and vacuum atmospheres

Property	Hydrogen Brazed	Vacuum Brazed
Yield point average	8,534 psi	12,600 psi
Ultimate tensile strength range	28,950 - 29,000 psi	15,500 – 35,000 psi
Ultimate tensile average	28,970 psi	22, 930 psi
Elongation % range	29 - 34	1.5 - 12
Elongation % average	31.5	5.0
Reduction of area % range	46.6 - 55	0.8 – 18.7
Reduction of area % average	50.7	7.6
Failure mode	Ductile in Cu	Brittle at the brazed joint

4.2 Shear Strengths of Glidcop to OFC Brazed Joints

Four test samples were prepared to evaluate the shear strengths of joints between Glidcop Al-15 and OFC (C101 per ASTM F68) brazed with 0.1 mm thick 50/50 Au-Cu foils. The samples consisted of a 6.35 x 25.4 mm Glidcop plate brazed to a 76.2 x 101.6 mm OFC block. The test setup is shown in Figure 6(a). In the previous study of hydrogen-brazed joints [1], the testing was stopped when the stress hit 6000 psi due to deformation in OFC material (Figure 6(b)). In contrast, the vacuum-brazed joints showed brittle failure (Figure 6(c)) with shear strength in the range of 5,018 - 6,608 psi.



(a) (b) (c)

Figure 6: Shear strength tests on brazed joints between Glidcop to OFC, (a) shear test set up, (b), hydrogen-brazed sample with large deformation [1], and (c) brittle failure in a vacuum-brazed sample.

4.3 Glidcop to Stainless Steel Braze Joints

Stainless steel (304 per ASTM A213) tubes of 19 mm diameter with a 1.65 mm wall thickness were vacuum brazed to Glidcop Al-15 (Figure 7(a)) with 50/50 Au-Cu alloy in inner and outer joint configurations. The brazed joints passed visual inspection and vacuum leak tests, MSLD at 1 x 10^{-9} cc/sec sensitivity. The sectioned brazed joints showed good joint quality (absence of porosity and lack of alloy diffusion) comparable to those brazed in hydrogen atmosphere (Figures 7(b) and 7(c)).

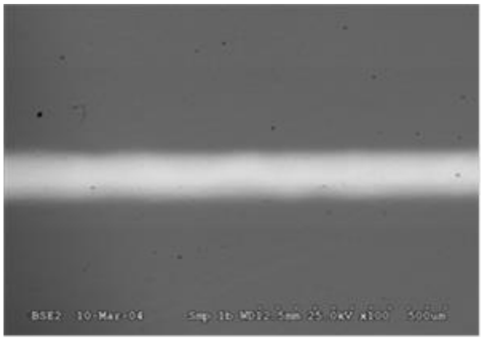
(a) (b) (c)

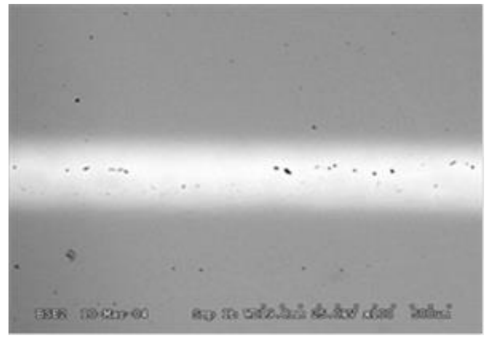
Figure 7: Braze joints between 304 stainless steel tubes of 19 mm diameter with a 1.65 mm wall thickness to Glidcop Al-15, (a) test specimens, (b) joints brazed in hydrogen atmosphere [1], and (c) joints brazed in vacuum atmosphere.

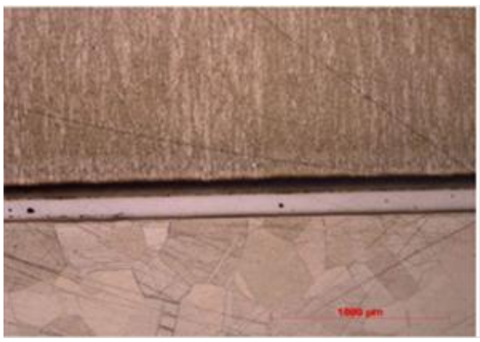
4.4 Metallographic analysis of braze joints

Scanning electron microscopy analysis was performed on the hydrogen brazed joints of the shear samples to demonstrate the bond quality of the as brazed joint (Figure 8(a)) and to quantify the effect of the second brazing cycle (Figure 8(b)). Samples were taken from sound portions of the brazed joints.

Optical microscopy was performed on the vacuum brazed joints of the shear samples to demonstrate the bond quality of the as brazed joint (Figure 8(c)) and a second sample which was exposed to two brazing cycles (Figure 8(d)). Results of the optical microscopy revealed that there were several areas where lack of bond existed between the filler and copper base material. However where the bond existed, the bonded area was good. There was some slight attack of the Au-Cu filler on the copper base material for samples exposed to a second braze cycle; however the integrity of the bond in those areas was acceptable.


(a) 2003 – Low Power SEM as brazed


(b) 2003 – Low Power SEM re-brazed (2 cycles)


(c) 2014 – Photomicrograph as brazed

(d) 2014 – Photomicrograph re-brazed (2 cycles)

Figure 8: SEM analysis of the hydrogen brazed samples (a) the as brazed joints were sound. (b) slight amount of internal voids showed after the second braze cycle. Optical microscopy was performed on the vacuum brazed samples (c) the as brazed joints were not 100% sound. (d) this section taken after a second braze cycle revealed a lack of bond that most likely existed from the original braze cycle. A slight amount of internal voids were observed (not shown) and there was some gold attack on the copper base material.

4.5 Summary of ANL Test Results

Results of mechanical tests, optical microscopy and SEM analyses show that brazing of Glidcop components in a vacuum atmosphere is not as robust as brazing in hydrogen atmosphere. Vacuum atmosphere brazing between stainless steel and Glidcop using 50/50 Au-Cu brazing paste is capable of producing UHV compatible leak-tight joints, however, the mechanical properties of these joints are not as strong as those produced by hydrogen atmosphere brazing.

These brazing tests also showed that:

- The vacuum brazing process was not as aggressive as hydrogen brazing in eliminating oxides and facilitating fusion and flow of the 50/50 Au-Cu alloy. This resulted in reduced shear and tensile strength of the joints.
- Increasing the braze temperature hold-point to 1020^{o}C when using Au-Cu foils acted to assist the disassociation process and to improve the quality of the brazed joints.

- Exposing Glidcop to 1020^{o} C for a short duration of time did not seem to affect the properties of the parent materials as evaluated by metallurgical and SEM analyses.
- 50/50 Au-Cu braze joints between OFC copper and Glidcop remained intact when exposed to multiple braze cycles.
- The Westgo FC-60 additive in 50/50 Au-Cu paste appeared to act as a fluxing agent improving flow and wettability on Glidcop and Stainless Steel joints in the vacuum atmosphere. This improved the success of the braze joints with paste over those made with foils.

5. Conclusions

A large number of Glidcop components were successfully brazed in vacuum atmosphere at NSLS-II and TPS. From visual examinations, micrographs and vacuum leak tests, the braze joints were determined to provide good UHV sealing and heat transfer properties.

A comparison of mechanical strengths of the brazed joints in vacuum and hydrogen atmospheres was performed at ANL. The results show that the mechanical strengths, while good in both atmospheres, were significantly higher for the joints brazed in hydrogen atmosphere.

References

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