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ANALYSIS OF GOLD-COPPER BRAZE JOINTS IN GLIDCOP® FOR UHV COMPONENTS AT THE ADVANCED PHOTON SOURCE

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Abstract

Dispersion-strengthened copper, Glidcop, is widely used in the design of high-heat-load, ultra-high-vacuum (UHV) components for synchrotron light sources. Furnace brazing of Glidcop to stainless steel or oxygen-free copper (OFC) for UHV service is usually done with gold-copper alloys in a reducing atmosphere of hydrogen. Copper plating of Glidcop, in a cyanide-copper bath, has been recommended to facilitate the quality of the braze joints by preventing diffusion of the braze alloy into the Glidcop base material. The copper-plating process however, introduces additional steps in the manufacturing process in addition to steps that are needed to insure blister-free plating.

A series of experiments for brazing AL-15 Glidcop with and without copper plating was conducted recently at Argonne National Laboratory Central Shops under the direction and funding of the Advanced Photon Source. Glidcop-to-OFC and Glidcop-to-stainless-steel braze joints were analyzed for structural strength and joint integrity for use in UHV service. In addition, an investigation was done to examine the re-exposure of Glidcop-to-OFC braze joints to thermal cycles, which would represent a second brazing cycle for components that require a multi-step brazing process for fabrication. The results of these brazing experiments are discussed in this paper.

1. Introduction

The Advanced Photon Source (APS) is a 7-GeV synchrotron light source that produces extremely intense x-ray beams with power densities exceeding 100 kW/mrad^2. Various absorbers, masks, shutters, and apertures are used to confine the beams within safe limits. These components are usually made from Glidcop ® AL-15, a dispersion strengthened copper consisting of pure copper matrix mixed with a small amount (0.28% by weight) of Al_2O_3 particles. The main advantage of using Glidcop is that it retains its superior mechanical properties (for instance, yield strength of about 400 MPa) even after exposure to high temperatures. Joining of Glidcop to oxygen-free copper (OFC) or stainless steel is required in most cases for a complete assembly of a component. Gold brazing with 35Au-65Cu or 50Au-50Cu alloys is commonly used for this purpose in addition to explosion bonding for simpler joints. Silver brazing with copper-silver eutectics has also been done with some success, but this requires nickel or copper plating of Glidcop to prevent silver diffusion along the copper grain boundaries [1].

Even with gold brazing, there is a tendency for gold to diffuse into Glidcop depending on the time duration in the brazing cycle above the liquidus temperature of the braze alloy. Copper plating of Glidcop will prevent such diffusion and is generally recommended [2]. Copper plating, however, adds another significant step in the manufacturing and quality-assurance process. A test run in the oven is required to ensure that the copper plating would remain blister free at brazing temperature. Several experiments were recently undertaken at the Argonne National Laboratory (ANL) to investigate gold brazing of Glidcop (AL-15) without copper plating. Each experiment was designed to examine the integrity of the braze joint for a specific application. In addition, a test was conducted to investigate the diametrical clearances proposed by designers on large diameters (7.8 and 9.8 inch) joints.

2. Brazing Procedure

All braze joints were made in the Thermal Technology AHP-1836-M oven shown in Fig. 1. The cylindrical working zone of the oven is 15 inches in diameter and 28 inches in height. The hearth, made of molybdenum, has a maximum temperature rating of 1600 °C. The temperature change with time in a brazing cycle is controlled by a Honeywell DCP 9000 programmable controller. The oven allows a vacuum, inert gas, or hydrogen environment for brazing. Brazing for this study was done with a flowing ultra-high-purity dry hydrogen atmosphere with a minimum flow of 10 liters per minute at 1 psi.

Figure 1: The AHP-1836M brazing oven.

Both 35/65 (35% gold and 65% copper) and 50/50 (50% gold and 50% copper) alloys were used for as braze fillers. The brazing alloys were used in two forms, a Westgo P90, 100-mesh paste and a 4-mil foil.

Machined surfaces were kept round or flat, as applicable, to within a 2-mil tolerance with surface finish of RMS 32 minimum. Selected samples of Glidcop were copper plated (in a copper cyanide bath) to a nominal 2-mil plating thickness. All parts were ultrasonically cleaned in a solution of 35% Citranox in deionized water heated to 90-100 °F. Glidcop, OFC, and stainless steel parts were cleaned separately in fresh solutions and then rinsed in deionized water.

All parts were then handled with clean Nitrile gloves to avoid skin contact. Brazing foil was taken fresh from sealed packages and handled with Nitrile gloves. Schematic time-temperature charts for brazing with 35/65 and 50/50 alloys are shown in Figs. 2 and 3, respectively. The time-temperature chart for re-exposure, either for second thermal cycle in a multi-step brazing or for repairing the initial brazing, with 50/50 alloy is depicted in Fig. 4. Certified type ‘K’ 1/16-inch-diameter Inconel sheathed thermocouples were used to monitor temperatures.

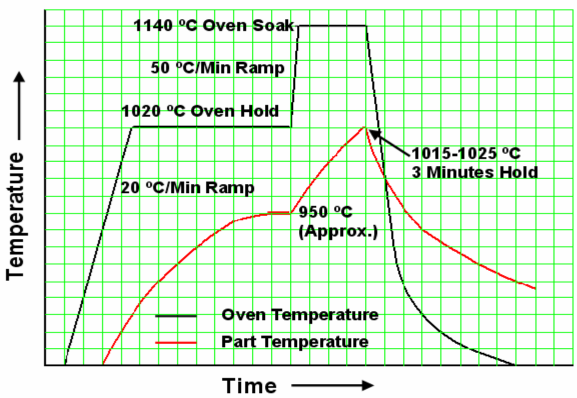


Figure 2: Schematic time-temperature chart - Glidcop brazing with 35/65 alloy.

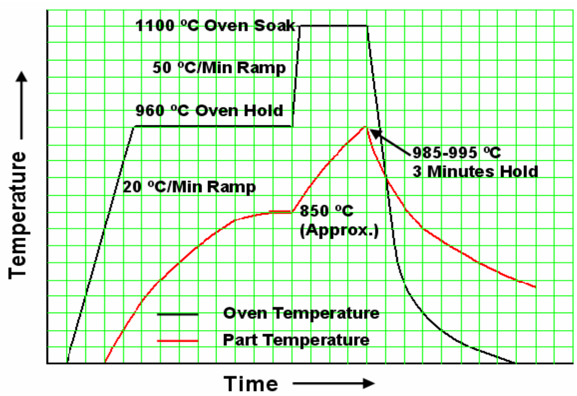


Figure 3: Schematic time-temperature chart - Glidcop brazing with 50/50 alloy.

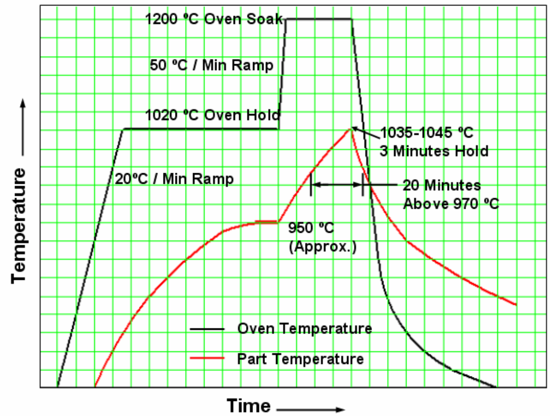


Figure 4: Schematic time-temperature chart – second thermal cycle for Glidcop brazing with 50/50 alloy.

3. Brazing Tests and Results

Four different tests were designed to analyze gold-copper braze joints in Glidcop while simulating actual braze joints of the various high-heat-load components at APS. These included (1) foil brazing of Glidcop AL-15 plates to OFC blocks, (2) brazing of tensile specimens of Glidcop and OFC, (3) small-diameter brazing of Glidcop to 304 SS (stainless steel), and (4) large-diameter brazing of Glidcop to OFC and 304 SS.

3.1. Foil Brazing of Glidcop Plates to *OFC* Blocks

Glidcop plates of 0.187-inch thickness and solid OFC blocks were machined to duplicate the joint configuration of the new APS photon shutters (Fig. 5).

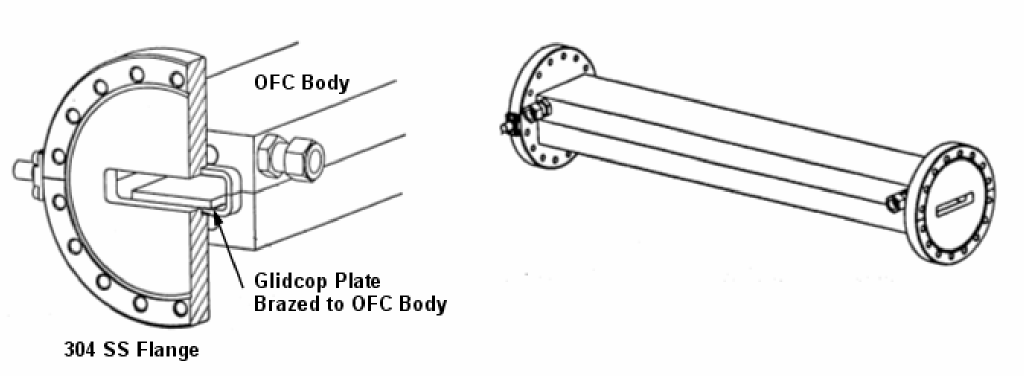


Figure 5. Glidcop brazing in the new APS photon shutters.

Virtual leaks in the joint were a major concern since the entire joint is contained in UHV. The test samples differed in the ways they were brazed as shown in the following table.

Table 1: Test Samples for Foil Brazing of Glidcop Plates to OFC Blocks

Sample	Description
1	Unplated Glidcop, 4-mil 35/65 brazing foil
2	Plated (with 2-mil copper) Glidcop, 4-mil 50/50 brazing foil
2A	Same as Sample 2, but re-exposed to another brazing cycle (as in multi-step brazing) with the Glidcop plate facing down
3	Unplated Glidcop, 4-mil 50/50 brazing foil
3A	Same as Sample 3, but re-exposed to another brazing cycle (as in multi-step brazing) with Glidcop plate facing down.

Evaluations of the braze joints were done with shear tests, metallurgical examinations, and SEM analyses. For shear tests, the samples were machined as shown in Fig. 6(a). Loads to failure were obtained in the configuration shown in Fig. 6(b).

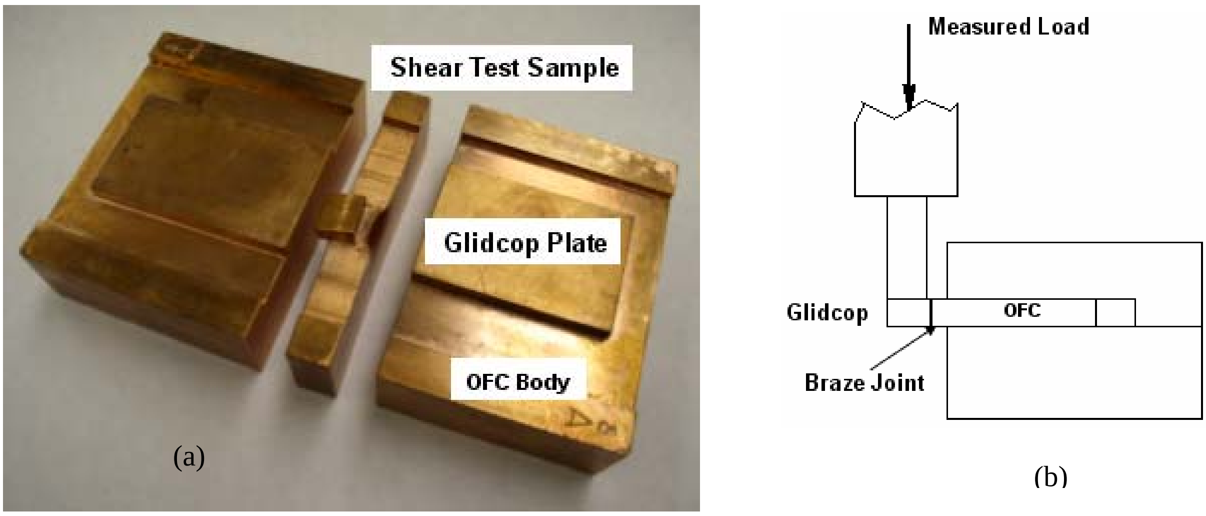
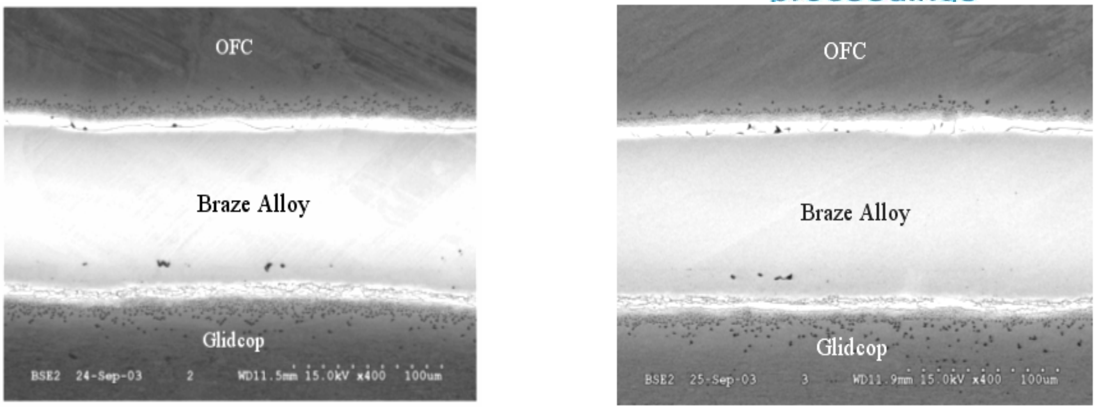


Figure 6: Shear testing of Glidcop plate brazed to OFC body: (a) one of the brazed samples sectioned for shear testing, (b) shear test configuration.

In all these shear tests it was not possible to achieve separation of the Glidcop plate from OFC. Excessive deformation of OFC near the braze joint changed shear stresses into a combination of shear and tensile stresses. After minimum shear stress exceeded 6000 psi in a sample, the load test was terminated.

Figure 7 compares SEM photographs of etched braze joints for Samples 2 and 3. As shown there is little difference in the diffusion zone or the chemistry of the initial braze joints whether or not Glidcop is plated.



(a) *(b)*

Figure 7: SEM photographs (X 400) of etched brazed joints with 50/50 alloy: (a) plated Glidcop, (b) unplated Glidcop.

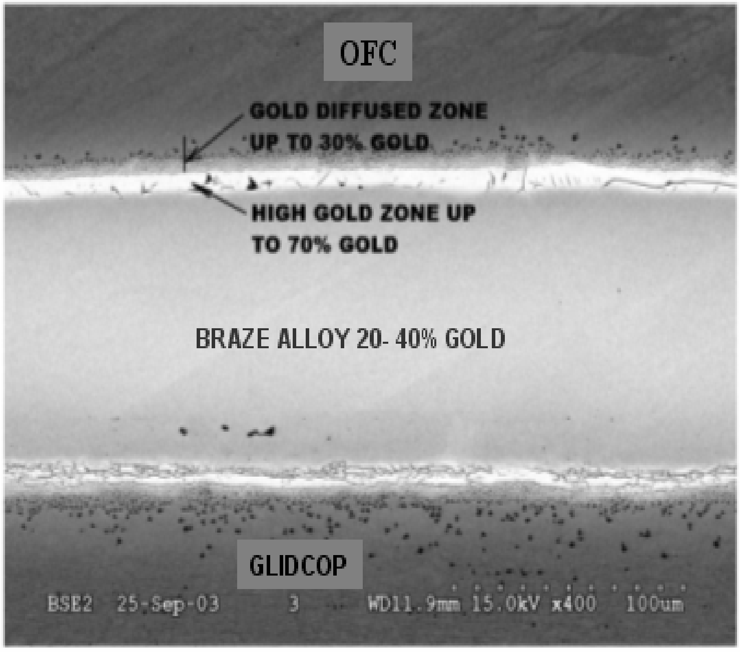
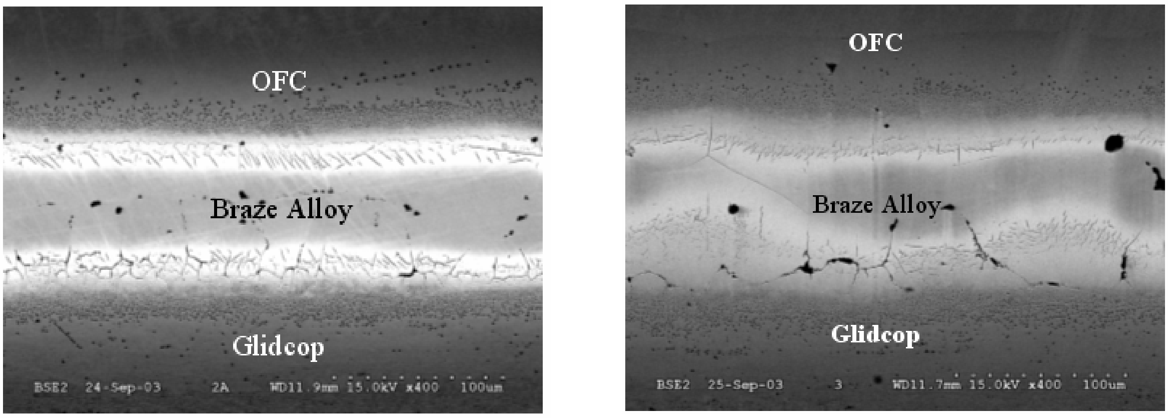


Figure 8: Typical chemistry of different zones of a braze joint (sample 3).

The chemistry of different zones of the braze joint of Sample 3, obtained by energy dispersive spectrography (EDS) with a Hitachi S-300N SEM, is depicted in Fig. 8.

Once the braze joints were re-exposed to another brazing cycle (Samples 2A and 3A), the diffusion in the plated and unplated Glidcop began to show a slight difference (Fig. 9). In the re-exposed joints, the “high gold” area of the braze alloy adjacent to the base metal was less defined and the percentage of gold in the parent metal increased slightly. The entire joint was more homogenous. This observation is consistent with what would be expected based on common diffusion theory.



(a) (b)

Figure 9: SEM photographs (400 X) of etched re-exposed brazed joints with 50/50 alloy plated Glidcop, (b) unplated Glidcop.

Each braze joint revealed the presence of some voids in the braze alloy portion of the joint. There is evidence that the number of voids increased slightly and the voids grew in size based on the time and maximum temperature. The resulting SEM analysis indicates that this may be due to two reasons: (1) coalescing of existing voids, (2) depletion of gold from the braze alloy. The use of the 4-mil-thick foil, allowed void formation to be small and discontinuous, thus minimizing their effect on leak tightness or strength. In addition, all joints were found to be sealed around the edges. This fact and the discontinuous nature of the voids lead to the conclusion that the presence of such voids will not result in a virtual leak.

There was more flow of the braze alloy when brazing with 35/65 foil (Sample 1). This resulted in a joint starvation at the top of the Glidcop plate. In combination with the higher temperature, the 35/65 joint on unplated Glidcop revealed the most void formation at the top. At the bottom, where there was sufficient braze alloy, the void formation was comparable to the 50/50 joints.

3.2. Brazing of Tensile Specimens of Glidcop and OFC

Unplated Glidcop bars were brazed with 4-mil 50/50 foil to OFC bars in a configuration shown in Fig. 10. The bars were then machined to 0.505-inch tensile test specimens per ASTM Standard E8. A test sample and two samples that were tested to failure are shown in Fig. 11 (a) and (b), respectively.

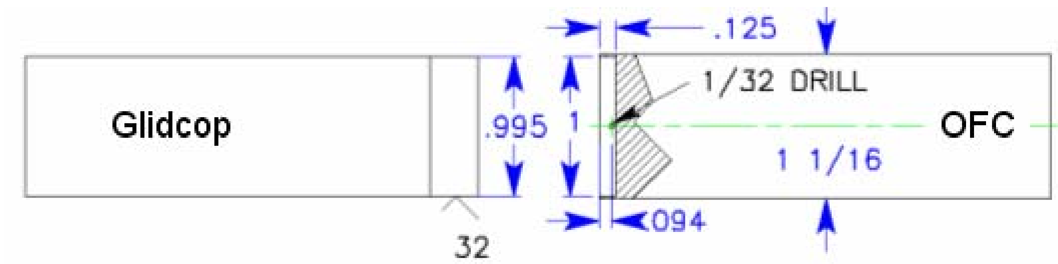


Figure 10: Brazing configuration for tensile test specimens.

(a)

(b)

Figure 11: Tensile testing of Glidcop to OFC braze joints – (a) a tensile specimen, (b) samples after tensile tests.

The tensile test results for the two samples, #02 and #03, are given in Table 2. The samples failed in OFC rather than at the braze joints as can be seen in Fig. 11(b).

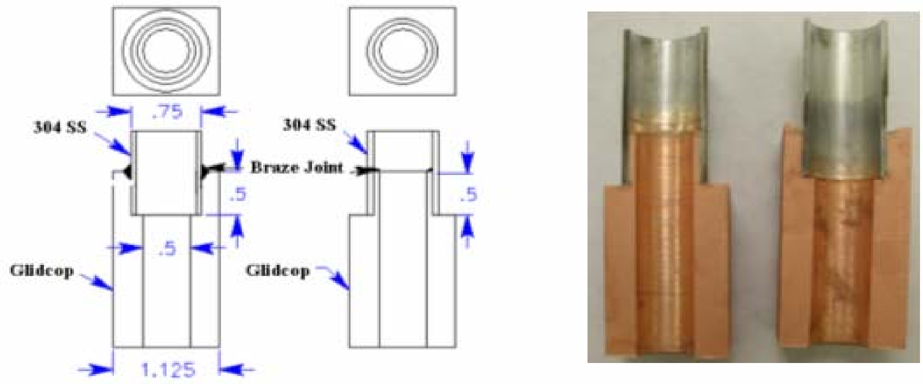
Table 2. Tensile Test Results from Two Brazed Samples

Sample	**02**	**03**
Diameter	0.505 in	0.504 in
Area	0.2 in^2	0.1995 in^2
Yield (0.2% offset)	8,592 psi	8,476 psi
Ultimate tensile strength	28,997 psi	28,947 psi
Elongation	34%	29%
RA	46.5%	55%
Failure	Ductile in OFC	Ductile in OFC
Modulus	19,430 ksi	14,890 ksi

3.3. Small-Diameter Brazing of Glidcop to 304 SS

These brazing tests were to compare the quality of braze joints in two configurations as shown in Fig. 12(a). In the first configuration, a 0.75-inch-diameter 304 SS tube is placed inside an unplated Glidcop tube with a diametrical clearance of 2-5 mils. In the second configuration, the same size 304 SS tube is placed outside an unplated Glidcop hub. In both cases, brazing was done with a 50/50 paste.

Mass spectrometer helium leak detection testing (MSLD) was performed on both of the brazed samples. The two samples were leak tight with no response with a 10^{-9} cc/sec calibrated MSLD. Following the leak tests the samples were sectioned and metallurgical micrographs were prepared as shown in Fig. 12(b). An examination of the micrographs revealed that the braze joint was slightly starved in the second configuration because there was a smaller shelf of Glidcop available on the inside for placing the brazing paste.



(a) (b)

(a) brazing configurations *(b) sectioned samples.*

Figure 12: Small-diameter brazing of Glidcop to 304 SS

3.4 Large-Diameter Brazing of Glidcop to OFC and 304 SS

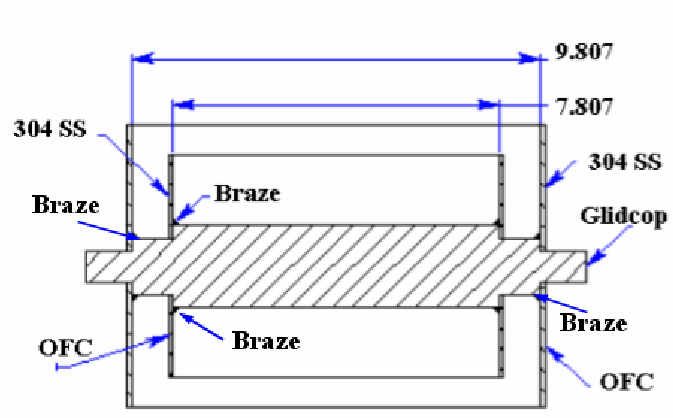


Figure 13: Braze joint configuration for large-diameter brazing of Glidcop to OFC and 304 SS.

A large section of Glidcop was machined for brazing along 7.8-inch and 9.8-inch nominal diameters (Fig. 13); on one side to two OFC rings and on the other side to two 304 SS rings. Diametrical clearances between the mating parts were from 5 to 7 mils. Brazing was done with 50/50 paste applied to Glidcop shelves inside the nominal diameters.

MSLD and metallurgical analyses were conducted on the joints after brazing. MSLD indicated that the braze joint between Glidcop and 304 SS was not leak tight at the 9.8-inch diameter. Figure 14(a) shows the test piece after it was sectioned into three pieces. A cross section of braze joints can be seen in Fig. 14(b). A visual inspection of the joint revealed that the braze alloy did not flow through the joint as indicated in Fig. 14(c). Metallurgical analyses showed significant deformations at both diameters at the joints between Glidcop and 304 SS. The braze joints between Glidcop and OFC were found to be satisfactory.

(a) (b) (c)

Figure 14: Large-diameter brazing of Glidcop to OFC and 304 SS – (a) sectioned sample after brazing, (b) cross-section of braze joints, (c) lack of braze alloy in Glidcop-to-304-SS-joint.

For the Glidcop-to-304-SS joints, a calculation was made for the needed diametrical tolerance. Thermal expansions of the Glidcop (AL-15), OFC, and 304 SS at the brazing temperature of 950 ºC are 0.0201, 0.0190, 0.0205 inch/inch, respectively [3,4]. These data show that, with initial diametrical clearance of 5 to 7 mils, there would be interference fit between Glidcop and 304 SS at 950 ºC. The amount of diametrical interference would between 1.6 to 3.6 mils for 7.8-inch diameter, and between 3.8 to 5.8 mils for 9.8-inch diameter. Because of this interference, the braze alloy could not flow through the joints, and the joints themselves were deformed.

4. Conclusions

Results from a series of experiments for brazing Glidcop (AL-15) to OFC and 304 SS have been presented. The following conclusions can be drawn from these experiments:

1. Although helpful in preventing diffusion of gold into Glidcop at temperatures above 980 °C, cyanitic copper plating is not required to obtain high quality, leak-tight joints when oven brazing Glidcop to 304 stainless steel or Glidcop to OFC.
2. 50/50 alloy is a better choice for brazing Glidcop material due to its lower brazing temperatures. In addition, the alloy is more sluggish at the liquidous temperature required for brazing. The sluggishness of the alloy can be an advantage or disadvantage. In joints that require the alloy to travel long distances, or have narrow diametrical clearances, this sluggishness will be counterproductive to good-quality vacuum-tight joints. The ability of the material to travel in joints of various materials, joint lengths, diametrical clearances, and thermal cycles is a topic that requires further investigation.
3. Void formation in 50/50 braze joints of plated and unplated Glidcop are more a function of joint clearance, surface finish, and liquid filler metal availability than absorption of gold into the parent metals. Having sufficient filler metal available is paramount to successful vacuum tight joints. Foil joints using 4-mil foil will result in leak-tight joints when the joint clearances and surface finish are appropriate.
4. The room temperature diametrical clearances for OFC and Glidcop brazed with paste alloy should be 2 to 5 mils.
5. The room temperature diametrical clearances for stainless steel joints and Glidcop are sensitive to the diameter as the differences in thermal coefficient of expansion is significant. More detailed research is needed in this area to test joints with diametrical clearances that agree with calculated values.
6. 50/50 alloy braze joints can be used, reheated to 1040 °C, and held over the melting point of virgin 50/50 alloy for up to 20 minutes without sacrificing joint integrity

provided the joints contain sufficient braze material. Use 4 mils of braze material as a minimum.

7. Shear and tensile strengths of 50/50 braze joints in Glidcop to OFC with proper clearances will exceed the strength of parent OFC material.

5. Acknowledgments

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