

BRAZING TECHNIQUES AND ALLOYS FOR ACCELERATOR RF COMPONENTS

R.B. Turner and J. Ungrin  
 Accelerator Physics Branch  
 Atomic Energy of Canada Limited  
 Research Company  
 Chalk River Nuclear Laboratories  
 Chalk River, Ontario K0J 1J0

Summary

Techniques have been developed for brazing thin flat sheets and for using electron beam heating to provide braze melt temperatures in situations where furnace brazing is not possible. These techniques are discussed and the results of a survey of braze alloy resistivities are presented.

Introduction

High power rf structures capable of operation at 100% duty factor are being designed at the Chalk River Nuclear Laboratories as part of a program to develop high current accelerators. These structures are usually made of OFHC copper to provide both good electrical and thermal conductivity. They generally consist of several components that must be joined by brazing. For structures such as the relatively thin vanes of a radiofrequency quadrupole (RFQ) accelerator, large areas of thin copper plate must be brazed over the cooling channels needed to remove the high average heat load introduced by cw operation. Satisfactory brazes require joint spaces less than 40µm thick and it is very difficult to keep thin plate adequately flat unless it is held with mechanical connectors. A braze technique using mechanical connectors has been developed.

High electrical conductivity must be maintained in a brazed structure for areas conducting high rf currents. Although electrical resistivity in thin joints may not appear significant, braze alloy frequently flows out over adjacent surfaces. If it is impossible to remove surface coatings after brazing, the alloy chosen must have a low resistivity. When a structure requires several successive brazes at decreasing temperatures it is difficult to find enough high conductivity alloys. Most suppliers do not have resistivity figures for their alloys. Resistivity measurements have been made for alloys covering a wide range of melting points.

Mechanical Connector Selection

Although dead weight loading may be adequate in some cases, it is difficult to apply adequate uniform loading in relatively small brazing furnaces. Most mechanical connectors - screws, clips, rivets, etc. - must be removed after brazing. If they cannot be removed they must be made of OFHC copper and become an integral part of the structure. Near the centre of large plates only screws and rivets appear suitable. Screws and screw clearance holes would have to be manufactured to tight tolerances to assure good brazing. Although OFHC copper rivets are not readily available they can easily be made by heading bar stock. Rivet holes do not require close tolerances because the riveting operation expands the shank. In

normal practice the hole may be up to 3% oversize. To obtain good electrical conductivity the rivet heads and shanks should be brazed. Rivet head brazing requires either sheet or wire braze alloy inserts.

A convenient stock size for brazing wire is 0.76 mm. When this wire size is used under the head, the head diameter must be about 3.2 mm larger than the shank, i.e., a diameter ratio of 2.0:1 for the small rivets and 1.67:1 for the larger rivets. Most head shapes are designed for 1.5 to 1.9:1. Only the flat head shape has a 2.0 diameter ratio. Countersunk heads have a 1.85 ratio. This means that conventional heads are satisfactory on the larger rivets but the smaller rivets need slightly oversize heads.

Sufficient rivet shank must project beyond the plate to form a proper head and fill the slightly oversize hole. When rivets with a 25 mm grip (total plate thickness) are used the excess length needed to form a head is shown in Table 1.

Table 1

| Rivet Size | Head Type   | Head Dia. | Head Length | Head Length/D |
|------------|-------------|-----------|-------------|---------------|
| 3.2        | button      | 6.4       | 4.8         | 1.5           |
| 3.2        | countersunk | 6.4       | 9.6         | 3.0           |
| 4.8        | button      | 8.0       | 5.6         | 1.17          |
| 4.8        | countersunk | 8.0       | 4.0         | 0.83          |

Rivet Tests

Two tests were made. Each contained two rivets of the above four types. One assembly used 0.0076 mm thick braze alloy washers under the heads and sheet alloy between the plates. The second assembly used 0.76 mm braze wire rings under the heads by counterboring the holes 1.5 mm oversize. These recesses were flat bottomed and 0.9 mm deep. The plate-to-plate braze used 1.27 mm wire. In all cases the alloy was 72 Ag 28 Cu.

After brazing, the braze wire assembly was leak tight. The braze shim assembly did not leak around the rivets. It did have serious leaks between the plates in the spaces between 4.8 mm rivets. Unless parts are heavy and free to move together when the alloy melts, it appears sheet braze alloy should be avoided.

The wire braze piece was machined to remove the rivet heads. About 0.25 mm was removed from the plate where there were countersunk heads. Approximately 1 mm was removed where there were button heads to get below the wire insert counterbores. Following head removal both pieces were

Table 2

**BRAZING ALLOY RESISTIVITIES**

| Alloy | Composition (%)              | Trade Name                             | Liquidus °C | Solidus °C | Form mm                 | *Resistivity ( $\mu\Omega$ -cm) |
|-------|------------------------------|--|-------------|------------|-------------------------|---------------------------------|
| 1     | 50 Au<br>50 Cu               | 50-50 (WG)                             | 970         | 955        | 1.27 wire               | 9.7                             |
| 2     | 82 Au<br>18 Ni               | Nicro (WG)<br>Permabraz 130 (H&H)      | 950         | 950        | 0.051 x 12              | 31.2<br>(29.3)                  |
| 3     | 81.5 Au<br>16.5 Cu<br>2.0 Ni | Nicro 80 (WG)                          | 925         | 910        | 1.27 wire               | 17.2                            |
| 4     | 80 Au<br>20 Cu               | 80-20 (WG)                             | 910         | 908        | 0.76 wire               | 12.3                            |
| 5     | 65 Ag<br>20 Cu<br>15 Pd      | Palcusil 15 (WG)                       | 900         | 850        | 1.14 wire               | 6.0                             |
| 6     | 58 Ag<br>32 Cu<br>10 Pd      | Palcusil 10 (WG)                       | 852         | 824        | 0.76 wire               | 4.2                             |
| 7     | 60 Au<br>20 Cu<br>20 Ag      | Silcoro 60 (WG)                        | 845         | 835        | 1.27 wire               | 13.0                            |
| 8     | 68 Ag<br>27 Cu<br>5 Pd       | Palcusil 5 (WG)                        | 810         | 807        | 0.76 wire               | 3.8                             |
| 9     | 71 Ag<br>28 Cu<br>0.75 Ni    | Nicusil 3 (WG)                         | 795         | 780        | 1.27 wire               | 2.6                             |
| 10    | 72 Ag<br>28 Cu               | Cusil (WG)<br>Braze 720 (H&H)          | 780         | 780        | 0.76 wire               | 2.3<br>(2.2)                    |
| 11    | 71.8 Ag<br>28 Cu<br>0.2 Li   | Lithobraz 720 BT<br>(H&H)              | 760         | 760        | 1.57 wire<br>0.051 x 27 | 4.2<br>4.2<br>(3.39)            |
| 12    | 63 Ag<br>27 Cu<br>10 In      | Incusil 10 (WG)                        | 730         | 685        | 0.076 x 25              | 7.1                             |
| 13    | 61.5 Ag<br>24 Cu<br>14.5 In  | Incusil 15 (WG)<br>Permabraz 615 (H&H) | 705         | 630        | 1.27 wire               | 9.6<br>(10.7)                   |

WG – Western Gold and Platinum Company  
 H&H – Hardy and Harman Company  
 \*Bracketed values are manufacturers listing

split through one set of rivets. A chromic and sulphuric acid mixture was used to etch the surface and make the braze alloy visible. All 3.2 mm rivet shanks were tightly brazed. Most 4.8 mm rivet shanks showed some porosity remote from the outer surfaces and this suggests insufficient braze alloy. All countersunk rivet heads showed some porosity. Apparently riveting did not fill the countersinks and the braze alloy was unable to bridge all gaps. The 3.2 mm countersunk rivets using braze wire were relatively good. Button head rivets were excellent once the surface was machined.

Resistivity Measurements

A survey of manufacturers' data and metals handbooks showed very little resistivity data for the brazing alloys commonly used. Readily available foil and wire samples, approximately 0.7 to 1.6 mm diameter by 200 to 600 mm long, were used for resistance measurements. A 2.5 A dc power supply and a high impedance (10 M  $\Omega$ ) digital voltmeter were used for the measurements. At 2.5 A the measured voltage drops were 15 to 500 mV. The error in resistivity is estimated to be less than 10%.

Voltage contact points were sufficiently far removed from the current contacts to eliminate end effects. No attempt was made to measure a series of points along the samples to independently establish the voltage gradient.

Where possible the measurements were checked against tabulated values. Because small changes in alloying element concentrations can produce large changes in resistivity, the apparent errors were sometimes as great as 25%. The measurement technique was checked by using samples of solid copper hook-up wire and Chromel-A heating element ribbon. The largest disagreement between the measured and tabulated values for these samples was 3.3%.

The composition and resistivity of the braze alloy may change during an actual braze depending on the metals joined and on the braze temperature. This composition may be further altered if the joint undergoes several temperature cycles near its melt point. The dc resistivity measurements must therefore be considered only as a guide in choosing a suitable alloy. Where tabulated values differ, the differences must be attributed to alloy composition difference. In Table 2, alloys 10 and 11 differ only in the small amount of Li in alloy 11. Clearly a small change in Li (manufacturer's listed range is 0.15 to 0.30%) can easily produce large changes in resistivity. Alloy compositions were not checked. Because the Li is consumed as a deoxidizer or flux a brazed joint may have a lower resistivity.

#### Electron Beam Welding

There are some copper structures, like drift tubes using permanent magnets, which cannot be sealed by brazing. Such magnets will not tolerate the braze temperature. Unfortunately, conventional welding techniques suffer because copper is a good thermal conductor and readily oxidizes. Such welds tend to be porous and rarely penetrate more than 3 mm. Electron beam welding was investigated because the heating is very localized and there is no risk of oxidation.

An attempt was made to improve the weld penetration by inserting a 72 Ag 28 Cu, 1.27 mm braze wire in a groove located 2.4 mm below the surface. Although the electron beam could not fuse the copper below this depth, the residual energy might melt the alloy and form a brazed joint to a much greater depth. One leak tight joint was formed with a 25 kV beam. The braze wire did not melt and only the outer 0.25 mm was tight (Fig. 1). Without a braze wire and using a 27.5 kV beam the outer 1.2 mm of the weld were leak tight (Fig. 2). At 30 kV the braze wire melted but the joint leaked (Fig. 3).

All welds were made with two revolutions of a circular disk turning at 38.1 mm/s. Temperature sensitive tapes on the inner surface indicated peak temperatures near 300°C. One successful test at 27.5 kV included a small permanent magnet. With a magnet in place, an iron ring and disk were used to shield both edges of the weld. Without this shielding the beam did not follow the weld surface. Further modifications may still permit combined electron beam welding and brazing.

#### References

1. Handy and Harmon, 850 Third Avenue, New York, NY 10011, "The Brazing Book".



Fig. 1 25 kV combined weld/braze. Disc at top joined to cylinder.

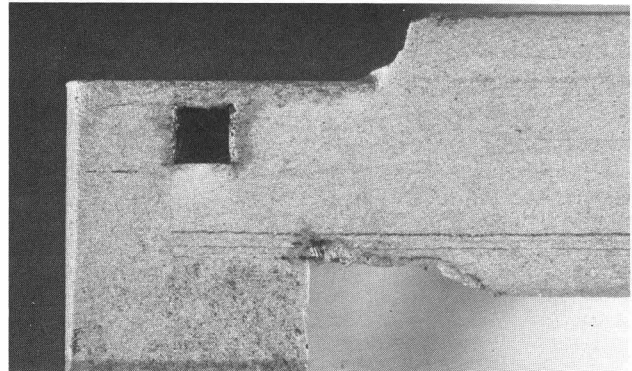


Fig. 2 27.5 kV weld without braze wire.

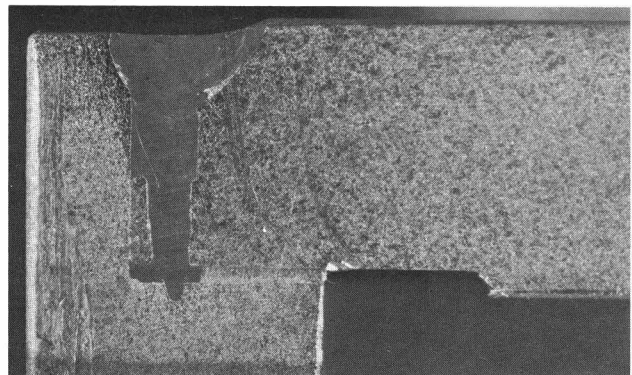


Fig. 3 30 kV combined weld/braze. Braze material melted and flowed to junction area.