Brazed joints and resonant cavities

D. Zambotto[1], P. Favaron[2], V. Palmieri[1,2], E. Vittone[3], A. Lo Giudice[3], A. Carnera[1], G. Tonini[4]

[1]Padova University, Science Faculty; [2]INFN-LNL, [3]Torino University; [4]TAV-High Vacuum Technology

I INTRODUCTION

I.I STATUS OF THE ART

Although Vacuum brazing processes are not the universal solution in the junction field, they are certainly the only method useful for making critical joint with good thermal conductivity and vacuum tightness.

It is expected a significant worsening of the niobium superconductor performance if brazed joints are present in regions where the radio-frequency field reaches high values, inside the body of niobium resonant cavities. However it doesn't exist in literature yet a methodical study about brazed joint and also the optimum parameters for the brazing processes.

I.II FINAL GOAL

The goal is two-fold: a) we will try to understand which limit exists for the application of the brazing technique to the construction of resonant cavities; b) we will try to calculate the copper diffusion depth inside niobium from MICROPIXE line-profile and explain why there is a significant worsening of the superconductor performance.

I.III SUPERCONDUCTING RESONANT CAVITIES

The success of a particle accelerator is mainly given by the performances of superconducting radio-frequency cavities. For linear accelerators, such as for example TESLA, it is required the achievement of Q-values as high as 10^{11} and accelerating gradients up to $E_{acc} \sim 40$MV/m. Several fabrication techniques of resonant cavities have been developed over the last years at INFN-LNL and specifically referring to quarter-wave resonant cavities (QWR) [1] for the acceleration of heavy ions, a whole accelerator has been built with copper cavities composed of brazed parts made superconducting by depositing a lead or Niobium thin film. In the following sections we will describe the role of brazing processes in the resonant cavities realization through the study of some common type of junctions: copper-steel and niobium-steel.

II BRAZING AND QWR CONSTRUCTION

Due to the problems connected with the Electron Beam Welding (EBW) technique (gas inclusion, cracks), the brazing technologies have been improved or developed in order to build QWRs. The replace of EWB (fig. 1, fig 2) is the logical consequence of the good results obtained with the brazing of the QWR external cylinder, beam ports and vacuum flange of the central shaft [2].

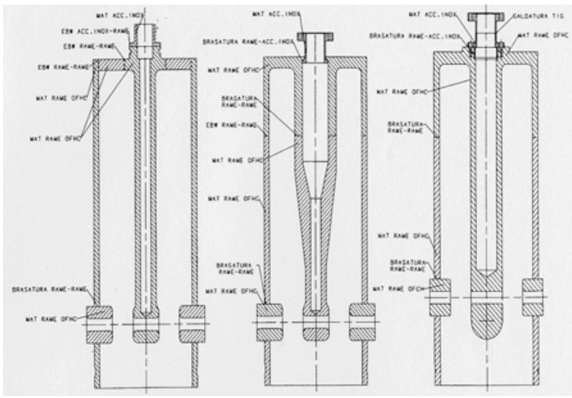


Fig. 1 Different QWR types. Brazing zone is evidenced

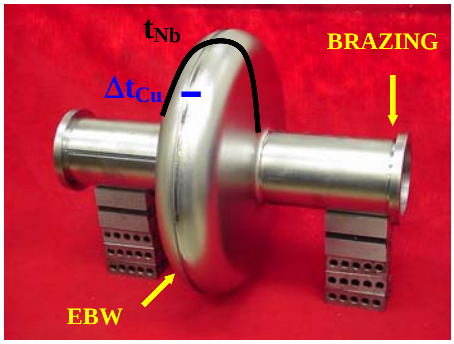


Fig 2. The EBW is unavoidable in high current regions, while it is mandatory for the flanges.

The hard brazing was adopted for joining the stainless steel collar to the copper on the upper part of the resonator and for welding the several Copper parts composing the resonator. After the brazing process, all the junctions have been tested at room and at liquid He temperature in order to proof vacuum tightness and the uniformity of thermal conductivity. Successively niobium is sputtered inside the QWR body [3].

The surface cleaning before brazing processes is crucial because of the strong link between joint cleaning and wetting of molten brazing filler metals.

Furthermore a good temperature control is fundamental to minimize liquation of filler metal (separation of the solid and the liquid portions) and to avoid a discontinuous brazing: in particular, the better is the temperature uniformity of the joints and the stronger are brazed joints.

The junction copper-steel is brazed with brazing filler alloy based on Ag, Cu and Pd.

The study of brazed joints is made through techniques that combine high sensibility with good lateral resolution such as SEM-EDS, MICROPIXE, SIMS.

The following pictures (fig 3 a,b) are the SIMS maps showing the silver and the copper regions. The mass signal, represented by the bright zones, is a function of primary cesium ion beam.

During the brazing process, the brazing fillet is melted and it flows by capillarity at the interface between the two surfaces to join. It diffuses for some tenth of a micron inside the contact surfaces, creating an intermetallic that normally melts at higher temperature than the original fillet. This explains why normally one can make subsequent brazings of the same piece at the same temperature and using the same eutectics.

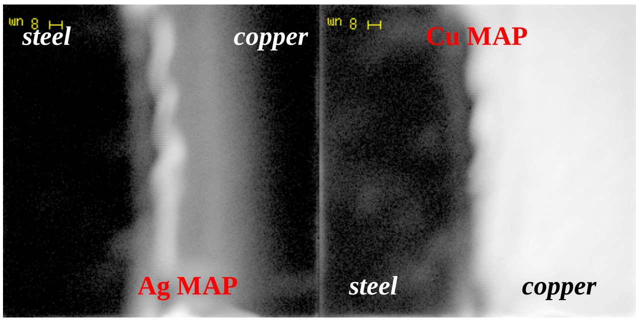
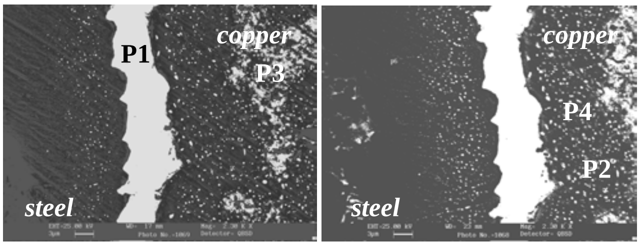


Fig. 3 SIMS Maps of the brazed joints.

Condition necessary but not sufficient in order to form such alloy is the constituent compatibility between base material and elements of brazing alloy.

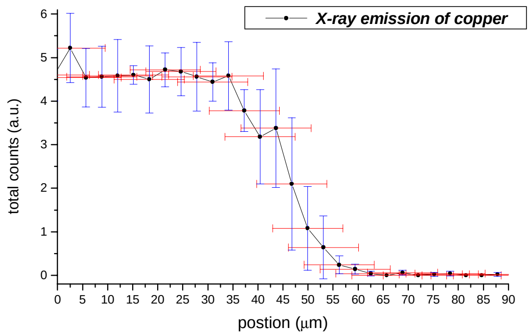
The following two SEM photos, collected with back-scattered electron, show the different zones in brazed region (P1,P2,P3,P4) which probably derive from phase segregation during the cooling step of the brazing processes.



The structure of these micro-phases in brazed region is unknown but the properties of each zone can be study respectively with diffraction techniques and micro-hardness tests.

III BRAZE AND Nb CAVITIES CONSTRUCTION

The superconducting niobium cavities were usually fabricated forming sub-components by deep drawing and joining them by electron beam welding (EBW). After some tests on brazed niobium cavities, such technique of construction came discarded since a meaningful worsening of the performances of the superconductor ($Q\sim10^7$ was noticed). The Q parameter can be assumed as a function of ratio between Δt_{Cu} and t_{Nb}, where Δt_{Cu} is the thickness of brazed region (copper diffusion depth inside niobium) and t_{Nb} is the length of the body cavity. OFHC copper, is always used such as brazing filler instead than nichel that is ferromagnetics. At 4.2K and 500MHz Nb becomes superconductor and its superficial resistance is ~ $40n\Omega$ (at zero RF field power). Instead, in normal conduction state, the superficial resistance of copper is ~ $4m\Omega$ (calculated with the "skin effect" approximation at 4.2 K and 500 MHz). The MICROPIXE line-profile gives $\boldsymbol{\Delta t_{Cu} \sim 19\mu m}$ (the copper diffusion depth is assumed as the decreasing of copper X-ray emission from 90% to 10%). This is the main reason for which there is a significant worsening of the superconductor performance and so the brazing junctions must be realized far from the body cavities.



IV CONCLUSION

The brazing techniques replace with remarkable succeeding the EB welding in the realization of junctions between flange and cavity (steel - copper).

In the case of steel - niobium junctions, it is necessary to keep in mind that brazing filler alloy (Cu) can worsen the performances of superconductor. It is therefore favorable to adopt technique EBW for junctions near the body of the cavity where the RF field is max. The strong collaboration between private industries (in this case TAV - Tecnologie Alto Vuoto) and INFN LNL is fundamental in order to solve problems such as brazing that are important for several reasons: i) the improvement of basic knowledge of metallurgical processes; ii) the optimization of the construction technology of superconducting radiofrequency devices for particle accelerators; iii) the broadening of industrial know-how by means of the transfer from fundamental research to the industrial technology.

[1] V. Palmieri, *Superconducting Resonant Cavities*, LNL-INFN (Report) 051/91.

[2] G.P. Buso, P. Favaron, R. Pengo, *Cicli di preparazione e geometrie di accoppiamento per brasature in alto vuoto*, Vuoto, Vol. XXI, n. 3, Luglio-Settembre 1991.

[3] G.P. Buso, P. Favaron, R. Pengo, Tecnologie di costruzione di una cavità risonante a quarto d'onda (QWR), LNL-INFN (Rep) 012/88.